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RAILWAY COLOUR LIGHT SIGNAL
Preliminary Design

Prepared for
TRANSPORTATION DEVELOPMENT CENTRE
Transport Canada

Prepared by

J.H. Longheed
D. Wong

DAVIS ENGINEERING LIMITED
CONSULTING ENGINEERS
Ottawa, Canada

MAY 1984

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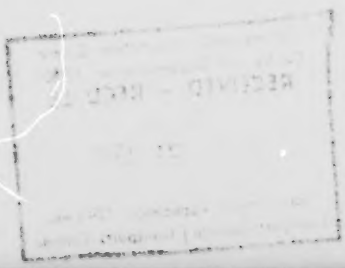

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Mechanical design expertise was provided by Mr. Laurence Corish, and his staff.

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17. Abstract

Current railway signals require regular replacement of the tungsten lamp and are increasingly prone to failure, either through lamp burn-out, mechanical filter lens movement or other electrical fault. This report describes the analytical and experimental preliminary design of a replacement signal unit utilizing arrays of high-luminance, narrow-angle light emitting diodes (LED's) for the light source. The new signal had to retain the single lens feature of present searchlight signals and be capable of displaying red, yellow and green aspects in both a solid and flashing mode, in addition to meeting established optical, electrical and mechanical/thermal design criteria.

Worldwide sources of LED's were researched and samples obtained. Side by side evaluations of luminance, spatial distribution and colour resulted in preferences for quantity purchases. Several optical concepts were tested in parallel with two emerging as being most desirable for further development. A progression of lab models were constructed and tested photometrically and visually. Physical and electrical integration with existing CN Rail signalling systems were investigated and chromaticity differences between existing signal specifications and available LED's were explored and minimized for red and yellow with the green achievable being less blue. The study concludes that two optical design concepts appear promising for colour light signal applications and recommends continuing the development into the prototype manufacturing and testing stage.

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17 Résumé Les feux utilisés actuellement en signalisation ferroviaire nécessitent le remplacement à intervalle régulier des lampes à filament de tungstène ainsi que des interventions de maintenance de plus en plus fréquentes, soit parce que les lampes ont brûlé, soit à cause d'un déplacement du filtre, soit pour toute autre raison de nature électrique. Ce rapport décrit l'étude préliminaire analytique et expérimentale visant à utiliser des groupements de diodes électroluminescentes à luminance élevée et faisceau étroit (DEL) comme source lumineuse. Le feu de type nouveau devait cependant conserver la glace unique des projecteurs actuels en plus d'émettre une lumière rouge, jaune et verte tant continue que clignotante et répondre aux exigences optiques, électriques, thermiques et mécaniques courantes.

Une recherche des fournisseurs mondiaux de DEL a été faite et des échantillons ont été obtenus. Une évaluation comparative a été faite sur les plans de la luminance, de la répartition spatiale et de la couleur; elle a permis de réduire les choix possibles en vue d'achats en gros. Plusieurs systèmes optiques ont fait l'objet de tests en parallèle; deux ont été jugés prometteurs une fois mis au point. Différents modèles de laboratoire ont été montés puis testés dans des photomètres physiques et visuels. Leur possibilité d'intégration dans le système de signalisation de CN Rail a été étudiée des points de vue physique et électrique. Les écarts entre la chromaticité des DEL offerts sur le marché et les prescriptions courantes ont été déterminés puis amenuisés pour ce qui est de rouge et du jaune, le vert obenu étant moins bleuâtre. Le rapport conclut en disant que les deux systèmes optiques en question sont prometteurs pour ce qui est de l'application envisagée et il recommande que les travaux soient poussés jusqu'au stade du prototype et des essais.

18 Mots-clés	19 Diffusion
Signalisation. Chemins de fer. Feux. Projecteurs. Système optique.	Rapport restreint aux employés autorisés des ministères fédéraux ou des sociétés d'état, ou aux représentants désignés de ces derniers.

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1.0 INTRODUCTION

This report summarizes the research which was necessary in producing a thorough electrical, optical and mechanical design for a solid-state railway signal light. It also provides complete plans to build a functional prototype. In June of 1983, Davis Engineering responded to a Request for Proposal initiated by Transportation Development Centre (TDC) requesting development of equipment to improve the existing three-colour searchlight commonly used for railway signalling. The work statement was oriented to burnout protection for conventional (filament) lamps by mechanical means and elimination of physical movement of the three colour aspects (filters).

In response, Davis Engineering proposed a solid-state approach utilizing light-emitting diodes (LEDs), wherein development of arrays and other optics would permit placement of 3 colour of LEDs within the existing signal, thus eliminating both lamp burnout and physical movement to obtain colour changes. It was argued that recent and ongoing developments of LEDs were sufficient to provide reasonable expectation of success for what is admittedly a radical departure from current technology.

Subsequently, a modified work plan was established to provide an early indication of the development prospects of this idea. This plan concentrated on establishing LED sources, testing various optical configurations, demonstrating lab models and examining some facets of integrating this new technology with the existing signal system. Regardless of implementation, however, the fundamental idea of solid-state LEDs as the source of light was to be retained, because it elegantly addressed both lamp and colour mechanism reliability.

1.1 REPORT ORGANIZATION

Due to the parallel and distinct nature of the various topics investigated during the course of this project, the report is

broken into the usual introductory and conclusion sections plus eight other main body sections, each corresponding to an area of investigation.

All sections have a similar format, containing subsections for theory methodology, results and discussion. This divisioning maintains good continuity through each topic and allows groups of related figures to be conveniently placed at the end of each section.

2.0 PROJECT OBJECTIVE

1. To design a railway colour signal light with a significantly reduced susceptability to lamp burnout and possibility of electro-mechanical failure compared to existing models.

2. To prepare plans and specifications for the fabrication of a prototype signal.

3. To prepare a work plan for the next phase of work leading to development of a successful operating signal.

2.1 DESIGN CONSTRAINTS

The original design constraints were expressed in the revised work statement from TDC. Further constraints surfaced during regular Steering Committee discussions. The priority and stringency of the various constraints were also explored in committee discussions. A general list of constraints and considerations is shown below broken into optical, electrical and mechanical categories.

Optical:

1. Beam width should be at least as broad as the existing signal.

2. The three colours should all project through the same lens.

3. The three colours should all lie within American Association of Railways (AAR) specifications for chromaticity.

4. The intensity should be sufficient to meet the railway distance visibility criteria.

5. There should be no moving parts.

6. The lamp life should be significantly increased over existing lamps.

7. Service and alignment should be possible in the field.

8. Coloured reflections or phantoms from headlights should be eliminated.

Electrical:

1. Fail safe design principles should be followed such that any component failure never causes a less cautious colour indication.

2. The signal should be controlled using the existing railway signal control system, incorporating a minimum of wiring changes.

3. The new design should not use more power than the existing lamp.

4. The circuitry should be able to withstand normal temperature and humidity extremes of Canadian weather.

5. The signal should work reliably with normal signal voltage fluctuations.

6. The signal should survive transient voltage surges as specified by CNR.

Mechanical:

1. The signal should be able to withstand shock and vibration to standard railway specification levels.

2. The signal should be structurally capable of

maintaining alignment during transportation and conditions of use.

3. The signal should be able to survive normal extremes of Canadian weather.

4. The signal should be mechanically compatible with the unit(s) it replaces.

2.2 PROJECT SCOPE AND WORK STATEMENT

The project scope described by the task list below was originally defined in the detailed work statement from TDC.

1. Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedure for the work, in consultation with members of the Steering Committee, and submit the work plan within two weeks of effective commencement date.

2. Meet with members of the Steering Committee at the commencement of the work and at periodic intervals of no greater than two months thereafter throughout the duration of the project.

3. Validate optical concepts of the proposed new signal, using a full scale model but restricted to only the red colour if impractical to include all three colours and demonstrate to Steering Committee members at contractor's workshop.

4. Develop electrical concepts for colour logic, circuitry and protection and design for high reliability and compatibility with existing signal.

5. Develop mechanical/thermal concepts for new signal.

6. Develop preliminary design for full-scale

breadboard unit.

7. Fabricate one breadboard signal. Test it and an existing seachlight signal in a laboratory for beam characteristics and submit them to Steering Committee for milestone review

8. Modify the design, as necessary and prepare plans and specifications for the signal in sufficient detail to enable fabrication of a prototype signal. Plans shall be prepared on Mylar and in accordance with current engineering office standards.

9. Prepare a Work Plan for the next stage of the signal development project which should include the fabrication of a prototype signal and the testing and performance evaluation of the prototype.

10. Prepare a final report of the project in accordance with the requirements set out. Include copies of the preliminary plans and specification of the new colour signal to be used as part of a tender package to accompany the final report, under separate cover.

The original work schedule shown in Table 1 was derived from this detailed work statement.

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	1	2	3	4	5	6	7	8	9	10	11	12	PLANNED PRÉVU À L'ORIGINE	ACTUAL PRÉSENTEMENT	E.T.C. À VENIR
.0 WORK PLAN															
.1 VALIDATE OPTICS															
.2 ELECTRICAL CONCEPTS															
.3 MECH./THERMAL															
.4 PRELIM. DESIGN															
.5 MODEL FAB. TEST															
.6 FINAL DESIGN															
.7 FINAL REPORT															
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ACT. PRÉSEN. / E.T.C. BY MONTH PRÉVISION POUR CH. MOIS														ACTUAL COÛTS RÉELS	E.T.C. À VENIR

TABLE #1 PHASE 1 WORK PLAN

3.0 LIGHT EMITTING DIODES

The search for the best LED's was started by compiling a comprehensive list of manufacturers.(See Appendix B) All of the manufacturers were then contacted and invited to supply specifications for their products. In order to judge which LED's were best suited to the signal light applications, a set of selection criteria had to be devised. Some of the relevant specification categories are listed below:

OPTICAL AND VISUAL

1 - luminance (brightness)
2 - chromaticity (colour)
3 - light beam angle
13 - LED life span
5 - Spectral line half width

ELECTRICAL AND MECHANICAL

9 - durability (mechanical and electrical)
6 - power consumption
7 - operating voltage
12 - efficiency

OTHER LED ATTRIBUTES

4 - LED size
10 - cost
11 - availability
8 - operating current

TABLE 2 LED SPECIFICATION LIST

It was apparent from the beginning that normal diffused LED's could not compete with the luminance of the existing lamp; therefore the search was rapidly concentrated on finding the LED's with the highest luminance. High luminance LED's are characterized by a reflector bowl behind their active element

and clear epoxy lenses in front, both of which tend to concentrate the light into a narrower beam.(See Figure 1) Using 100 millicandella or greater as a criterion for luminous intensity reduced the manufacturers' list to fewer than 10. Although luminous intensity figures were always available, other specifications, such as chromaticity and light beam pattern, were not usually adequately specified.

3.1 SOURCING METHODOLOGY

The deficiency in specifications naturally led to a strategy of obtaining samples of all possible candidates and comparing them to each other. Production of custom LED's optimized for signal light application was discussed with five manufacturers but the only useful customizing available in small quantities was deflanging. As can be seen from the sample in Fig. 2 this modification allows tighter packing of LED's. A flat array of deflanged LED's covers about 15% less area than the same number of LED's with flanges. Several pieces of apparatus were designed and built to facilitate comparisons of luminance, chromaticity and beam pattern. The LED comparison device shown in figure 3 has the capability to compare luminance and chromaticity, by eye, of any combination of LED's in a 3 x 3 matrix. The LED currents (which control LED luminance) can be individually set from 0 to 100 mA in 7 discrete steps, thus allowing LED's with different current specifications to be compared. Figure 3a shows the 7 switch positions and corresponding currents for each of the nine rotary switches on the test box. This feature also allows the effect of over or under driving a LED to be compared to the standard condition.

The single LED tester in figure 4 is used to view beam patterns and angles of individual LED's. It may be used with various lenses and pattern viewers such as those shown in figure 5. The circuit of this tester, shown in Figure 4a provided 3 LED current settings. Both pieces of apparatus discussed above were also used in conjunction with various coloured filters, such as the ones shown in figure 6, to investigate their effect on LED colours. The most convenient "meter" for these tests

was the human eye, which is the ultimate discriminator of colour and is also useful for comparing luminance. There was enough variation between LED's that a simple comparison by eye was sufficient to select the highest luminance LED's with the best colour. Models did not usually use the optimum LED's because of delivery schedules and availability. In fact LED technology is in a period of rapid change and better LED's are being developed continuously.

3.2 LED SOURCING RESULTS

A list of the 61 suppliers and the letter that was sent to them appears in Appendix B. The list also indicates which ones responded. The response varied from not interested, to specifications, to samples. In addition, local representatives and distributors were contacted for data books, pre-production samples, new product rumours and announcements. During the course of this contract alone, several promising developments have taken place, including the Stanley H2000 (the highest luminance to date), the National NSL7310 (the best yellow colour) and three blue LED announcements.

Samples of 30 different types of high luminance LED's were obtained from a dozen suppliers, and tested for luminance, beam pattern and chromaticity. Testing was necessary because the most recently developed LED's have no published specifications.

Below is an abbreviated table summarizing the key specifications of the best LED's currently available. Appendix B contains all of the available manufacturers specifications for LED's above 100 mcd.

MANUFACTURER	PART NUMBER	LUMINOUS INTENSITY in millicandella	COLOUR/ WAVE LENGTH in nano meters	BEAM ANGLES in degrees	COMMENT
FAIRCHILD	FLV 104A	150	RED/679	4°	NARROWEST BEAM
HEWLETT PACKARD	HLMP 3750	125	RED/635	24°	
DATA DISPLAY	200-URCW	500	RED/660	~24°	
STANLEY	H 500	500	RED/660	~12°	
STANLEY	H 2000	2000	RED/660	~12°	*BEST RED LED
HEWLETT PACKARD	HLMP 3850	140	YELLOW/583	24°	*BEST YELLOW LED
DATA DISPLAY	200-UYCW	350	YELLOW/570	~24°	
STANLEY	ESAY 5701	~120	YELLOW/580	~24°	
NATIONAL	NSL 7310	~120	YELLOW/~585	~24°	*BEST YELLOW COLOUR
HEWLETT PACKARD	HLMP 3950	120	GREEN/565	~24°	
DATA DISPLAY	200-UGCW	200	GREEN/555	~24°	*BEST GREEN LED
STANLEY	ESBG 5701	~120	GREEN/555	~24°	

* Considered best for this application

TABLE 3 KEY SPECIFICATIONS OF THE "BEST" LED SAMPLES

The various other LED parameters were roughly the same for all LED's. The chromaticities of the best LED's are marked on the chromaticity charts in figure 7. These charts also show the AAR chromaticity specifications for colour signals. A rough idea of the actual colours may be seen on the corresponding colour chart in figure 8. See Section 4 for more complete explanations.

3.3 DISCUSSION

Several unusual LED's were obtained: one had a built in fresnel lens but it didn't produce a narrow beam; one had two LED's in series under one epoxy lens but the beam was very wide and could not be focussed by one lens because of the separate sources; and one had two different coloured LED's under one lens with similar focusing problems. The two-coloured device did show some colour mixing when both were on or alternated quickly, but blending was very uneven and the light was

diffused by the LED lens. In talking with several manufacturers' representatives it was ascertained that producing special LED's with custom specifications was definitely feasible if the quantities were high enough. Even blue LED's can be produced if there is a demand for several million. The optimal specifications for LED's in railway signal lights are not yet in high demand for other applications, so initiatives to start production of more suitable LED's may have to originate from the signal light application itself. The Canadian market alone could create sufficient demand for custom LED's if there was a committment to convert half of the existing signals to solid-state, and if an international market could be demonstrated, second sources of suitable LED's would certainly become available.

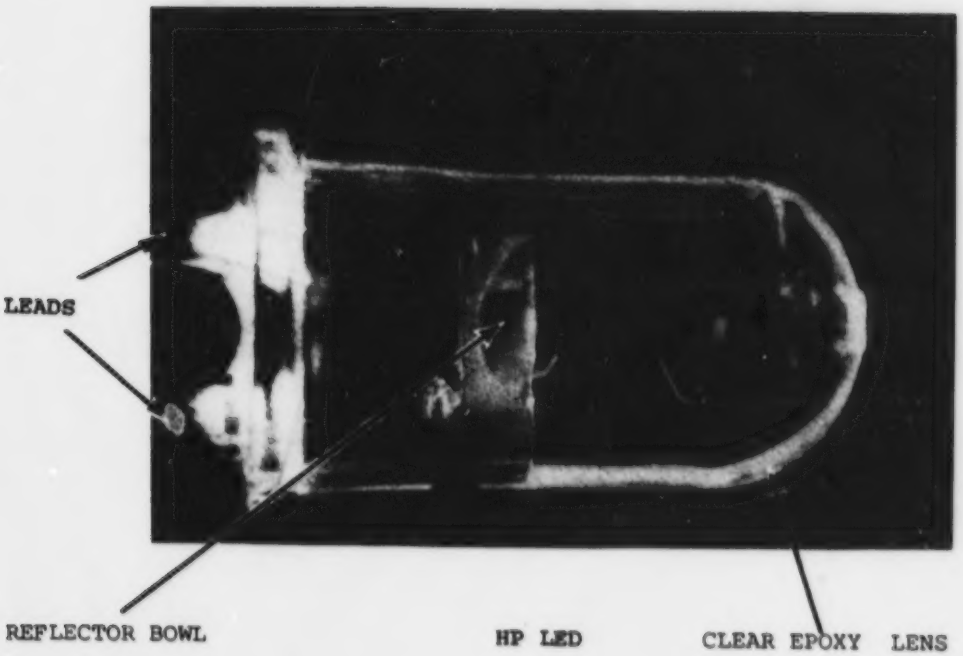


FIGURE 1 HEWLETT-PACKARD LIGHT EMITTING DIODE: SIDE VIEW

LED
TYPE: DATA DISPLAY
COLOUR: GREEN

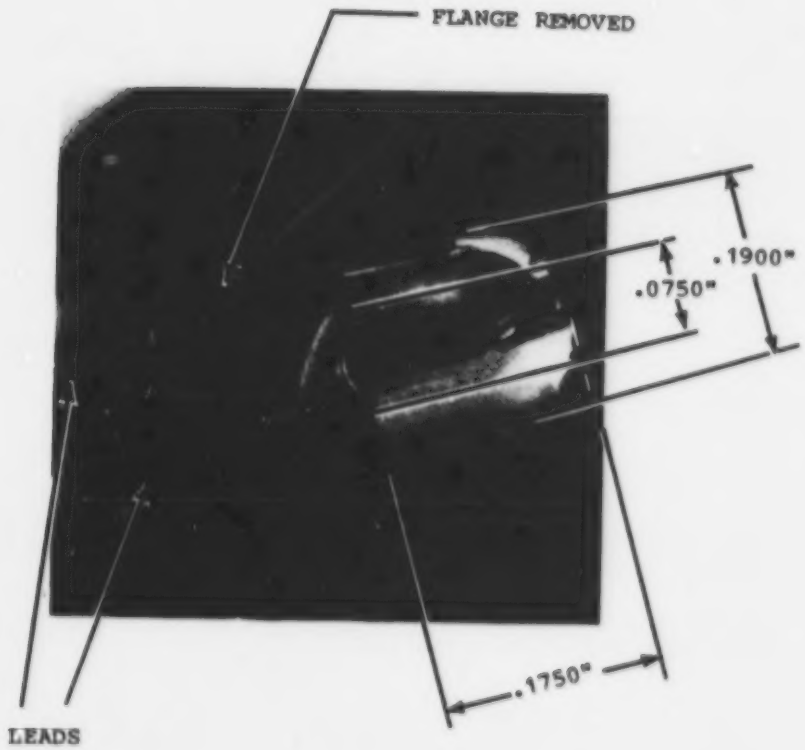


FIGURE 2 DEFLANGED LIGHT EMITTING DIODE

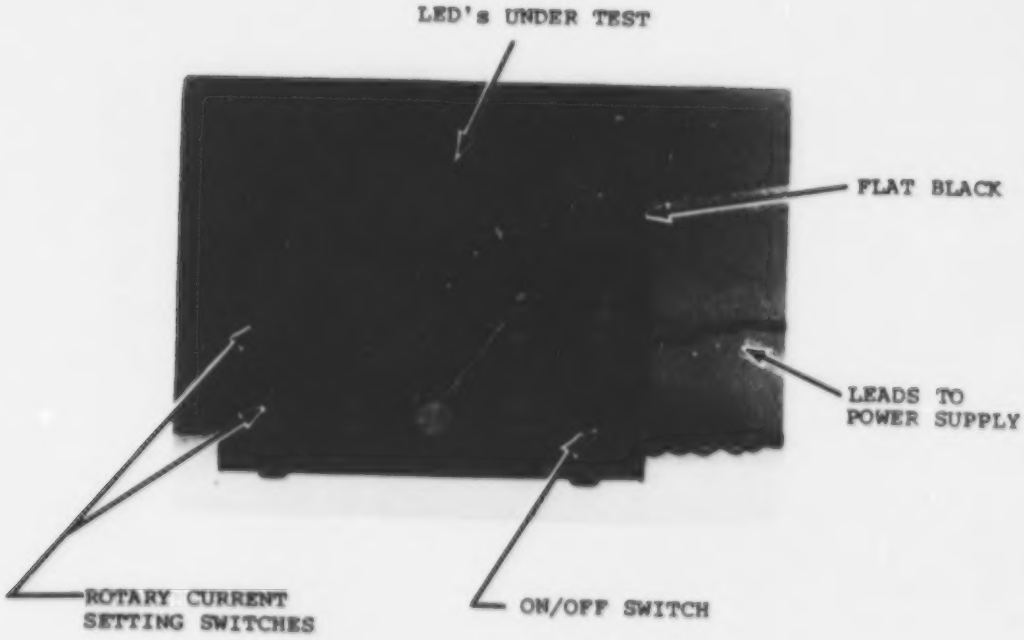


FIGURE 3 LED COMPARISON DEVICE

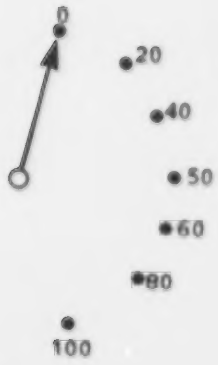


FIGURE 3a ROTARY SWITCH CURRENT KEY

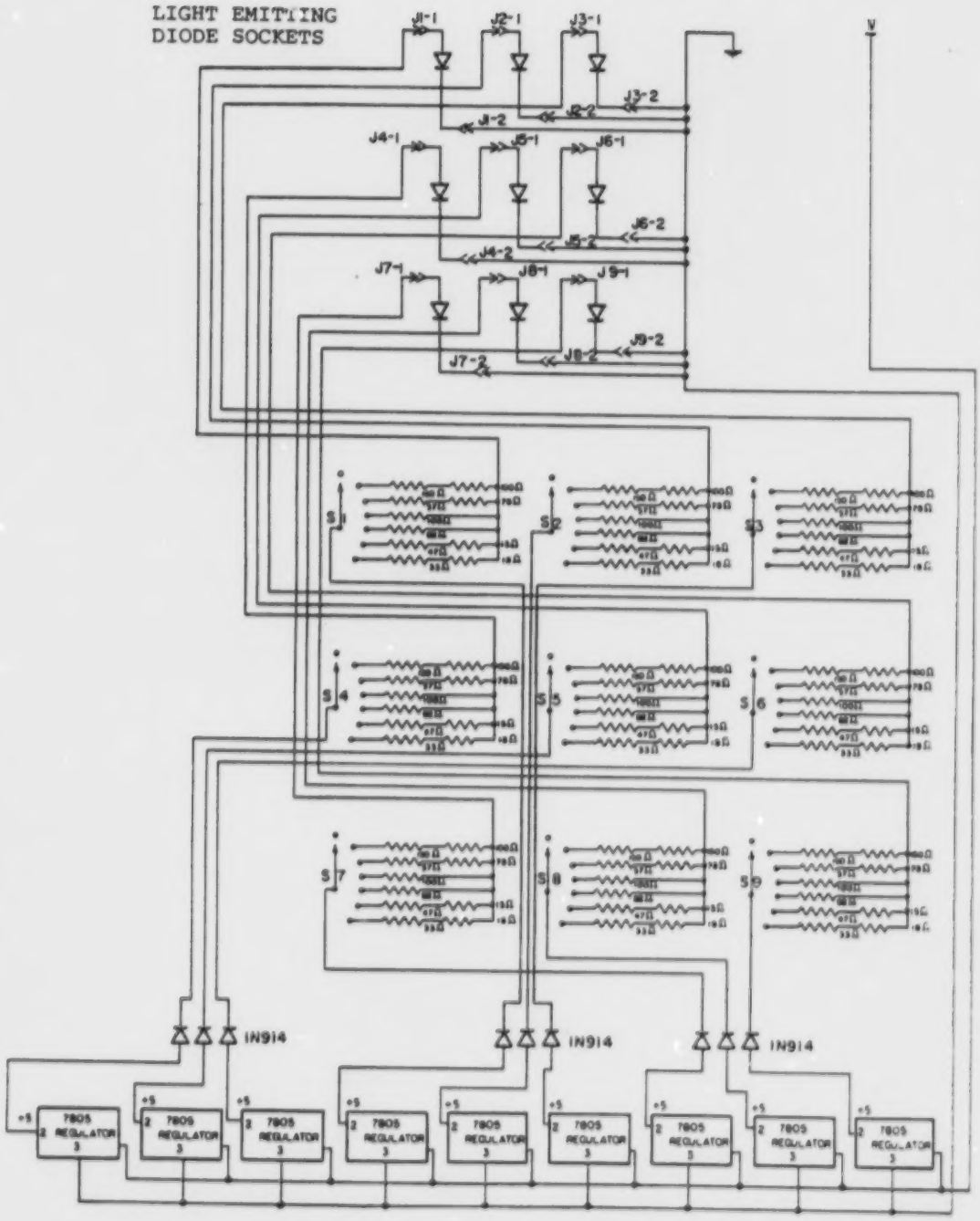


FIGURE 3b LED COMPARISON DEVICE SCHEMATIC

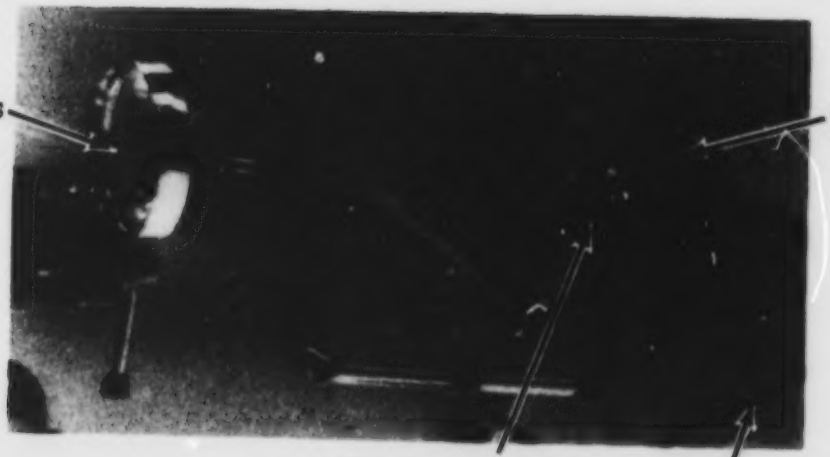


FIGURE 4 CONCEPT 3 14TH MODEL
SINGLE LED TESTER

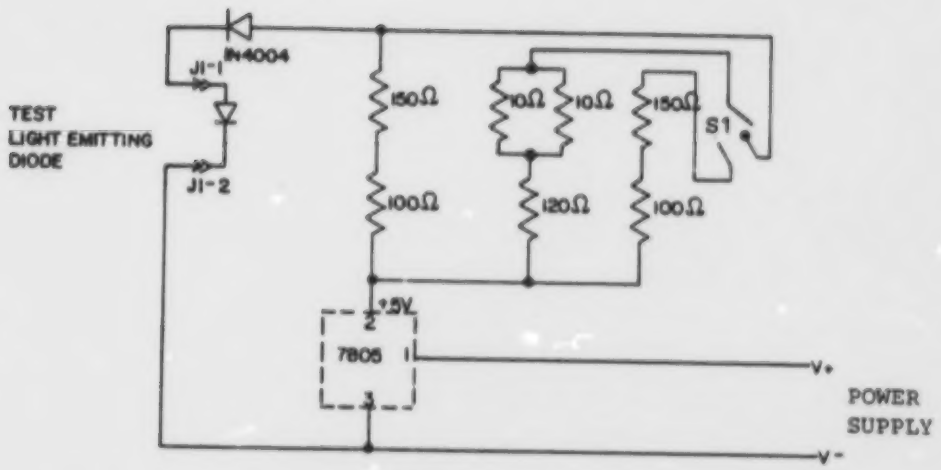


FIGURE 4a ELECTRONIC SCHEMATIC OF THE SINGLE LED TESTER ABOVE

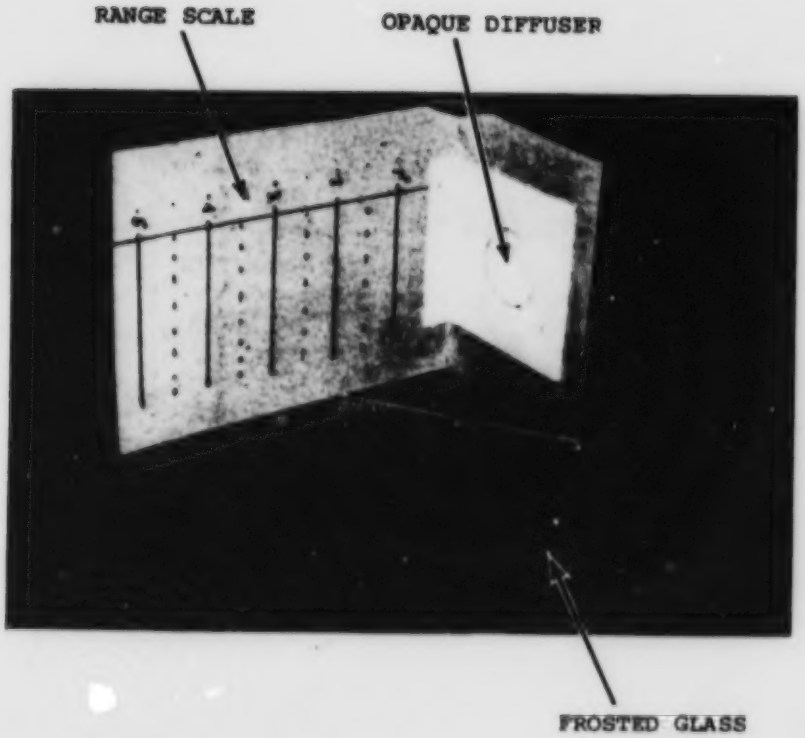
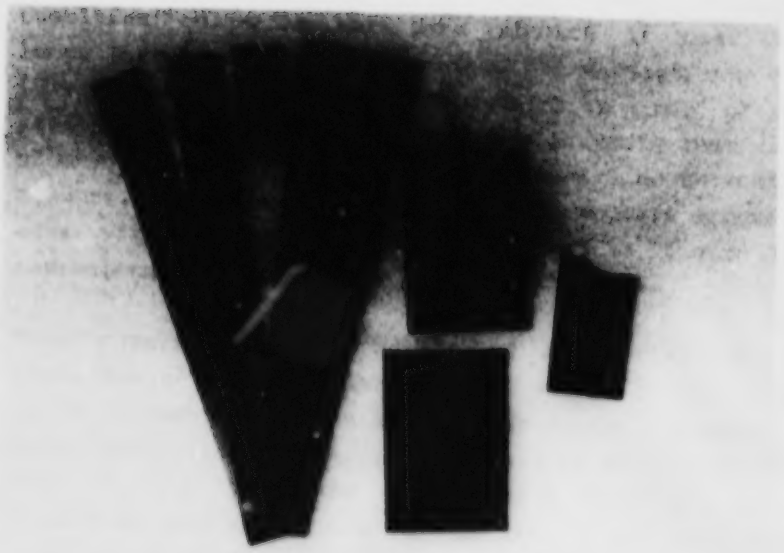


FIGURE 5 LIGHT EMITTING DIODE
BEAM PATTERN VIEWERS



VARIOUS TRANSLUCENT COLOUR FILTERS

FIGURE 6 CHROMATICITY TEST APPARATUS FILTERS

4.0 CHROMATICITY

LED's are almost monochromatic by nature as evidenced by typical spectral line half widths of 30 nanometers. This means that most of the light produced by an LED has a wave length within 15 nanometers of its most luminous wavelength. The resulting colour is very pure placing it near the spectrum locus (outer edge) of the standard CIE chromaticity chart shown in Figure 7 and Figure 8. This chart is a map of the colours seen by a standard observer with the property that all mixtures of any two colours will lie on a straght line between those two colours. The normal colour spectrum appears around the outer edge with wavelengths being indicated in Figure 7 and the corresponding colour being shown in Figure 8.

Monochromatic light may be blocked or partially blocked by a translucent colour filter but it won't change colour. The eye's perception of a colour may change, however, if the background colour changes. It should be noted that the colours seen in the CIE chart in Figure 8 have only been roughly reproduced and aren't exact. In fact no printing can show the true colours under arbitrary lighting conditions, because the visible colours are just reflections of ambient spectral components, and ambient light will have arbitrary proportions of the many possible spectral components.

4.1 TEST CRITERIA

The Association of American Railways developed a chromaticity standard for railway colour signals many years ago. This standard attempts to define signal colours which the widest range of observers will find unambiguous. The allowable colour boundaries are shown in Figure 7 by a solid line. In this project the colours of interest are green , yellow and red. Allowable greens cover a large section to the upper left, while the allowable yellows cover a narrow slot down the right side and the allowable red is right on the edge in the lower right corner.

4.2 TEST METHODS AND EQUIPMENT

The LED specifications were compared to the AAR chart and the LED's were compared to two existing signal lights. These tests indicated which directions the colours had to be shifted to meet AAR specifications. Attempts were made to shift the LED colours by shining them through coloured filters or changing the background colour and to mix colours by turning on different colours side by side. The equipment used to compare and filter LED light is described in section 3 and shown in Figures 3,4 and 6. A separate 3 LED circuit was put together to test colour mixing using a red, a green and a yellow LED in close proximity. See Figure 9.a. The schematic for this circuit is shown in Figure 9.b and indicates that all three LED's had the same current flowing through them. The colours may have been easier to mix if they had separately controlled currents.

4.2.1 Colour Alternatives

Colour discrimination and psychology including common human deficiencies, were discussed with Prof. B. Tansley, Human Factors consultant, Psychology Department of Carleton University. One technique to circumvent the chromaticity requirement was explored namely to flash the LED's at 7-10 H_z. This technique would augment chromaticity as a discriminator of signal state and allow easy recognition even by colour-blind observers. Another benefit could be that average power consumption is cut in half. High flashing rate is not an option with existing signals, since tungsten lamps cannot be turned on and off quickly however LED's have no such limitation. Flashing rate is limited only by the human eye which exhibits a well known persistence and recognizes flicker with increasing difficulty above 16 H_z. A short test was performed using a variable frequency variable duty cycle rectangular wave generator driving the model 11 array. When flashed at 8 H_z with a 50% duty cycle the array was easy to distinguish from a regular 1 H_z flasher and had an insistent

attention-getting quality not found in static signals. Another technique to augment discrimination of signals is to vary the shape of the source. LED's excel in this application since it is not necessary to block any light to create unique patterns, and no moving parts are required to control an array in switching to different patterns. Again colour-blindness is not a factor. Model number 12 used this principle as a by-product of trying to make a symetrical array of 3 colours having different numbers of LED's for each colour, Figure 36 shows the patterns used.

4.3 RESULTS

As expected, shining LED's through colour filters did not shift their colour much and the more their colour was shifted the more their luminance was decreased. As far as actual colours go: the red LED's were all well within the AAR boundary; the yellow LED's were mostly a little more yellow (about 6 nanometers) than the AAR specification which is slightly orange; and the green LED's didn't have enough blue spectral components. (The existing signal lights have a very bluish-green colour). The three best LED's maximum luminosity wavelengths are plotted as dark triangles on the chromaticity chart. (Figure 7)

The colour mixing of separate LED's (Fig. 9) did not work very well especially at close range. Placing a diffuser such as ground glass, or even a piece of paper, in front of the 3 LED's helped mix the colours but also scattered the light in all directions, rendering it difficult to collect and focus. Beam spreader roundels may encourage colour mixing but these devices also allow the light to be seen at closer range, where it is easier to distinguish point sources. Extensive testing was not undertaken since the mixing colours of interest are green with blue, and blue LED's are not yet in high volume production.

4.4 DISCUSSION

There is no problem with the chromaticity of red LED's, they are even redder than the existing lights. Standard LED technology permits a fairly continuous range of colours from red through orange and yellow to green so obtaining a suitable yellow LED is mainly a matter of finding a manufacturer who is producing close to the specified colour.

Green LED technology has a fairly long way to go to meet AAR specifications but blue LED's have been demonstrated by Sanyo, Panasonic and Siemens thus enabling a technological assault from the blue side of the specification as well as the green. Bracketing the AAR specifications like this does not necessarily imply that the perfect LED is on the verge of discovery especially since the blue LED's are based on an entirely different process (involving a Silicon substrate). The surest short term strategy is to utilize current technology and combine blue LED's with green LED's to create a blue-green array. The position of the Data Display green LED on the CIE chart in Figure 7 shows that it would take relatively little blue to 'pull' the green within the AAR specification boundary.

True mixing of blue and green into a homogeneous blue-green may not be necessary as a signal with both blue and green visible is likely to be as easy to distinguish as any homogeneous colour. This theory will have to be proven by observer testing.

Colour filters have three unattractive qualities:

1) They reduce luminous intensity by absorbing light.

2) They provide the possibility of a coloured reflection from a train headlight.

3) They don't shift the colour of a green LED far enough to meet the AAR specification.

Changing the background colour does shift the colour perception but only one colour background can be used and it only has an effect when illuminated.

Rapidly flashing lights appear to be a promising signalling technique but need more testing to determine their value. Flashing and changing shapes may also cause some confusion in the short term. Some shapes may make it difficult to notice if there has been a partial failure (ie. several LED's are not functioning).

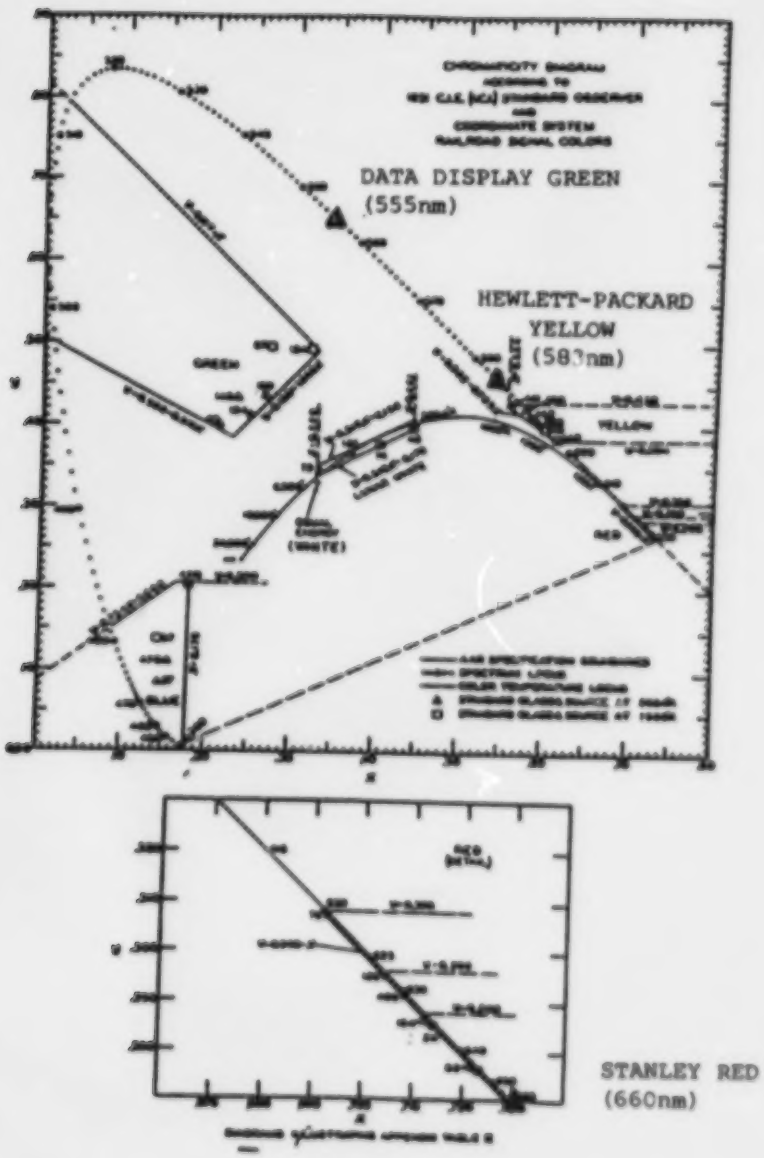


FIGURE 7 CIE CHROMATICITY CHART AND AAR SPECS

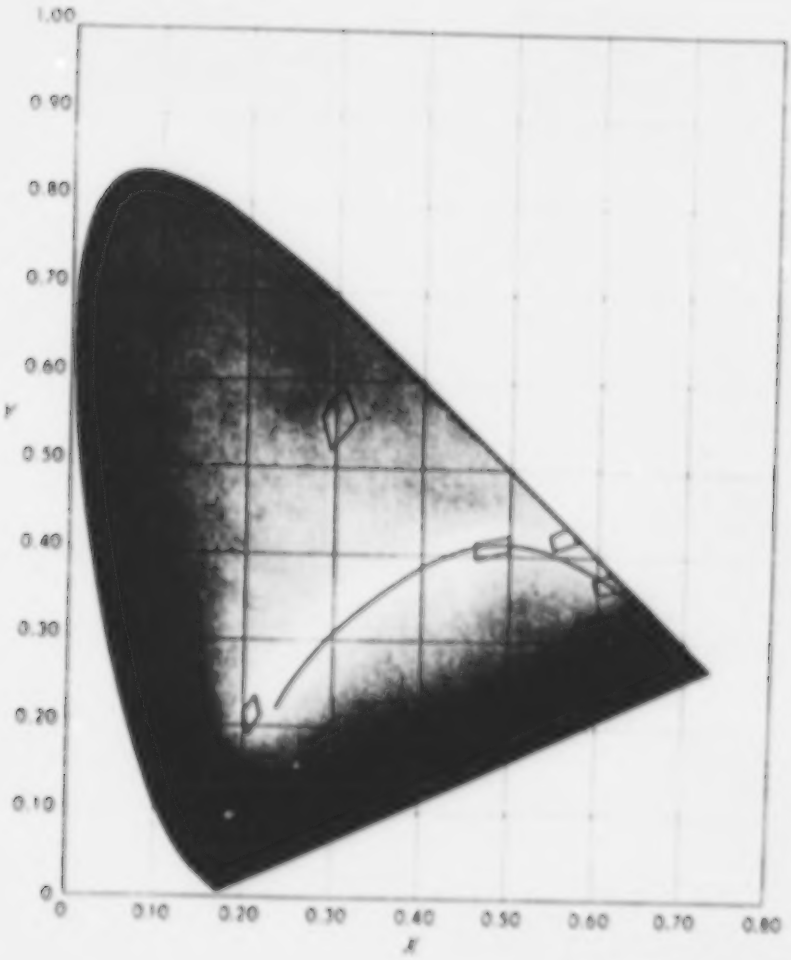


FIGURE 6 CIE CHROMATICITY DIAGRAM

LED's

TYPE	HLMP3750	HLMP3950	HLMP3850
COLOUR	RED	GREEN	YELLOW

FIGURE 9a COLOR MIXING TEST APPARATUS

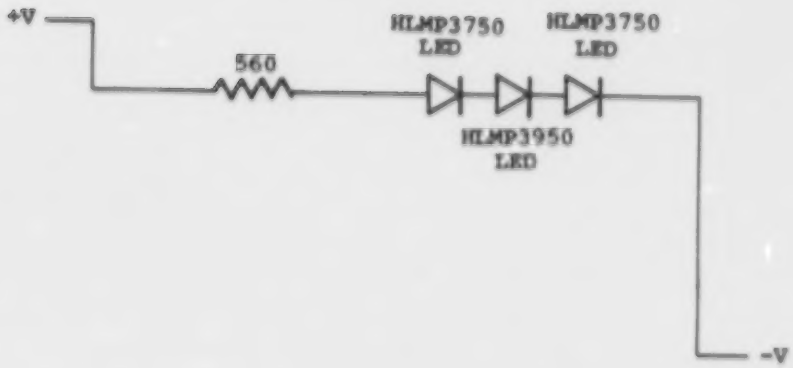


FIGURE 9b COLOR MIXING SCHEMATIC

5.0 LUMINANCE

Luminance is the measure of brightness of an area source or the ratio of luminous intensity to the projected area of the source. An area source will look like a point source if it is small enough or far enough away. The human eye perceives a source to be an area until the angle subtended by the source is less than about 1/30th of a degree. For the existing signal light to look like a point source it would have to be about 1200 feet away from the observer. A typical LED would look like a point source from 30 feet, but when viewed through normal seachlight optics the 'crossover' distance extends to 200 feet. It may become important to manipulate this distance when trying to mix colours from separate LED's. Technical discussion and definition of luminance appears in Appendix C.

The AAR specification for beam angle is that it should be at least 50% of its peak luminous intensity at angles of plus and minus .75 degrees. This means the beam width must be at least 1.5 degrees. Since wider beams are desireable the various models were designed with beam angles up to 4 degrees. A design tradeoff exists, of beam angle for luminance, which can be manipulated to enable some of the models to achieve higher luminance. For example, reducing a 4 degree beam to 1.5 degrees will increase the peak luminance by a factor of about seven.

5.1 TEST METHODS

All luminance measurements were taken 30 feet from the signal light where it could still be considered an area source. Although the eye is fairly good at discriminating which of two sources is brighter, a quantitative measurement of luminance is necessary to be able to determine beam angle and to accurately describe the difference in luminance between models and the existing lamp. Test equipment and procedures had to be found to characterize an existing searchlight beam and the beams produced by all models so that objective comparisons could be

performed.

NRC was contacted but did not have suitable apparatus for characterizing searchlights, so the apparatus and test procedures were designed and implemented in-house.

The luminance characterization procedure was designed to obtain beam profiles of angle versus luminance. A schematic of the apparatus is shown in Figure 10. Two luminance meters were set up level with the light being tested but 30 feet away. The light was then panned across the meters and readings were taken at every 20 minute increment of arc. The light was rotated through 8° total, to insure that the 4° of interest were scanned. Although the angles depicted in Figure 10 are shown as vertical the actual rotation was in a horizontal plane. Both meters used measure light coming in from a one degree cone, implying that everything in that one degree contributes to the reading.

It turned out that the front lens of the signal took up a little more than one degree, so by rotating about a vertical axis through the front lens it was possible to keep the meters measuring only light from the signal (turning the ambient lighting on and off had a negligible effect on readings). An in-house computerized plotting package was used to create graphs of beam luminance profiles and to superimpose various combinations for comparison purposes. The software source listing appears in Appendix D.

5.2 TEST EQUIPMENT

The one degree luminance meters are shown in Figure 11 on their fixed wall bracket. The Soligor Spot Sensor (in the middle) had an internal analog meter graduated by F-stop for photographic work. A modification was performed on the Soligor to allow accurate remote readings to be conveniantly taken with a digital volt meter. The voltage readings taken this way were approximately logarithmic with luminance. (as is the eye).

The Tektronix J6523 luminance probe (shown on the left in Figure 11) contained a direct digital readout in Foot lamberts. Specifications for both devices are shown in Appendix C

The signal light housing was mounted on a heavy duty panning table such that the axis of rotation passed through the front lens. This custom made stand which appears in Figures 12 and 13c has a hand cranked rotating mechanism graduated in 5 minute steps. A scaffold, for positioning models in the signal housing, was anchored at the back of the rotating platform as shown in Figures 14a and 14b.

5.3 TEST SEQUENCE

The Soligor was in operation several months before the Tektronix arrived and, since early testing was concentrated on Concept 1[1], the data for Concept 1 models were all collected using the Soligor. The testing sequence was primarily dependant on availability and delivery of key components: Concept 1 was tested first because it did not need lenses or scaffolding; Concept 2[1] was tested when the scaffolding arrived; Concept 2a was tested when the lenses were delivered etc.; Concept 3 was almost abandoned when it appeared that only a limited portion of the available light would be collimated, but recalculation showed it to be worth pursuing.

All models were tested for luminance, and luminance versus angle profiles were plotted for all prototypes containing more than 18 LED's. Plots were also produced for the 3 LED array in model 25 (concept 3). In addition, absolute luminance profiles were plotted for the two complete concept 2a three colour arrays and the existing light in all 3 colours.

Other tests included accelerated life tests running LED's at up to 5 times their rated current for 2 weeks, and flashing arrays at different frequencies to otain a colour or brightness enhancement effect.

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[1] See sections 7,8 and 9 for complete description

5.4 DISCUSSION

Using the 1° luminance meters at long range will require a high contrast between the signal light and any surroundings which appear in the one degree measurement area. This in necessary since the actual signal light will only cover a small part of the 1° and even low luminance surroundings may contribute significantly to the readings.

Although the scaffold on the rotating platform allowed accurate positioning of models the optimum position was often difficult to find. This occured because of the scaffold geometry the scaffold adjustment mechanisms, the different model sizes, the different model optical geometries, the cramped space, and the fact that a uniform 4 degree beam would not necessarily result if the model position was adjusted to give a peak luminance reading. Another problem which may occur is misalignment of the signal light in the one degree measurement angle of the meters. All positioning and alignment errors create uncertainty in the readings and usually detract from the results. Any such errors are estimated to be less than 5%.

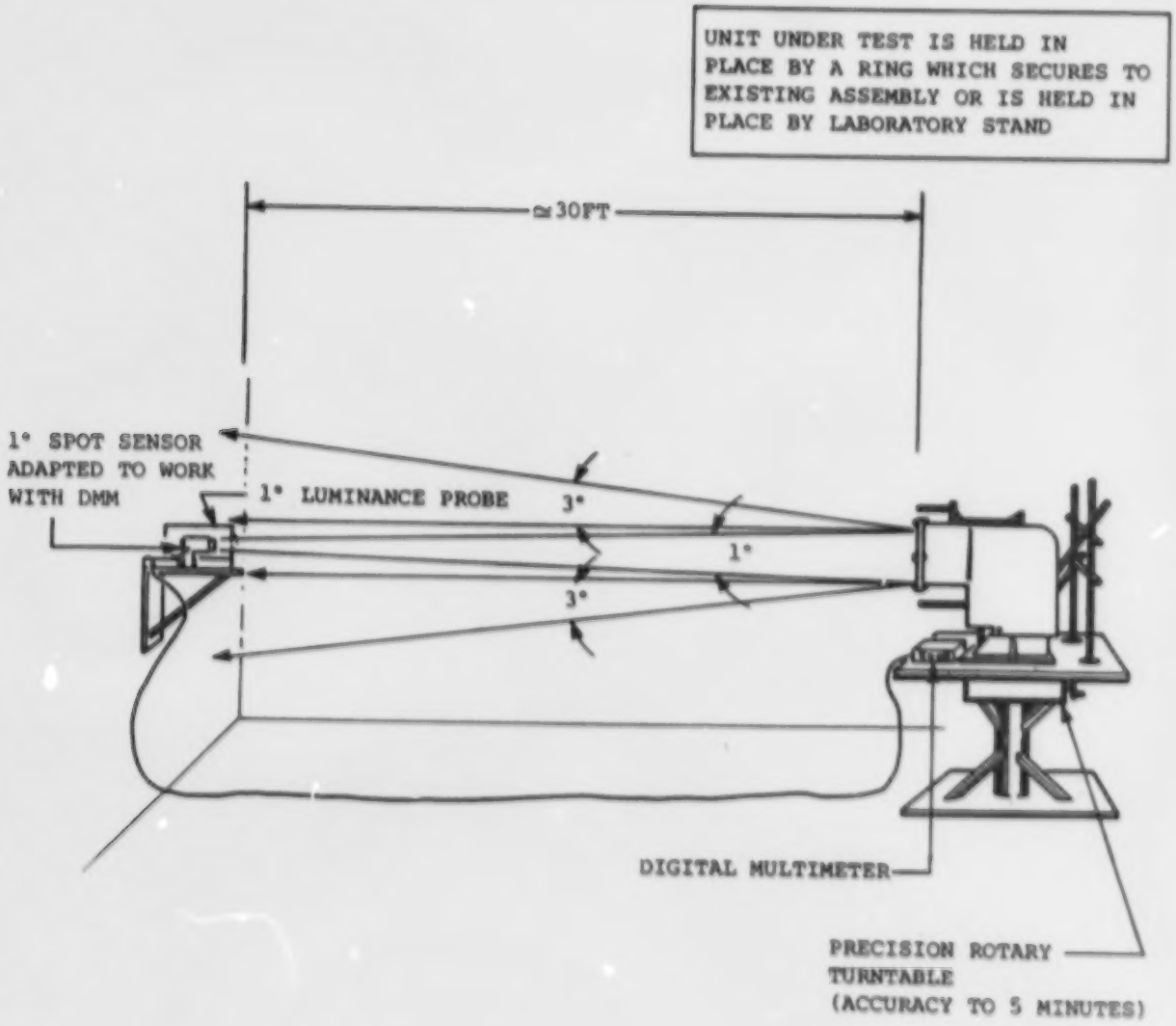
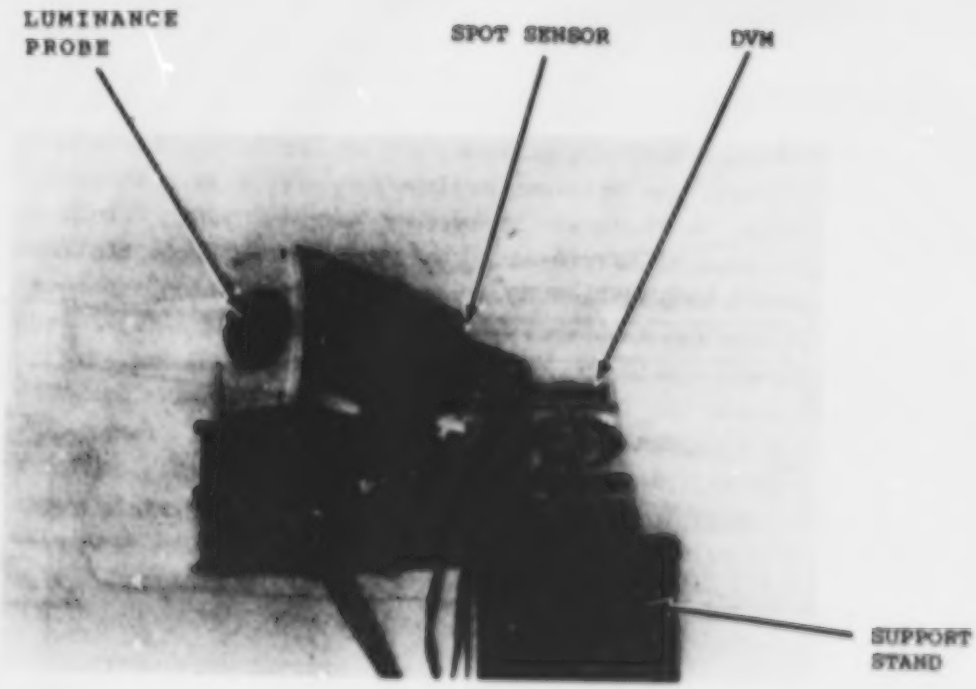

UNIT UNDER TEST IS HELD IN PLACE BY A RING WHICH SECURES TO EXISTING ASSEMBLY OR IS HELD IN PLACE BY LABORATORY STAND
≅30FT
1° SPOT SENSOR ADAPTED TO WORK WITH DMM
1° LUMINANCE PROBE
3°
1°
3°
DIGITAL MULTIMETER
PRECISION ROTARY TURNTABLE (ACCURACY TO 5 MINUTES)

FIGURE 10 LIGHT MEASUREMENT APPARATUS



LIGHT METERS

FIGURE 11 LIGHT MEASUREMENT APPARATUS

VIEW FROM THE LIGHT METERS

FIGURE 12 LIGHT MEASUREMENT APPARATUS

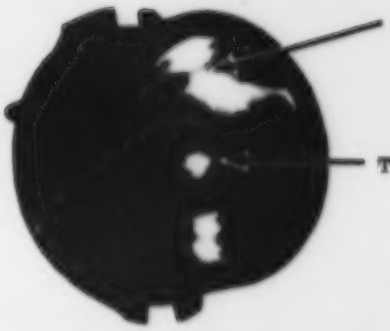


FIGURE 13a EXISTING LIGHT

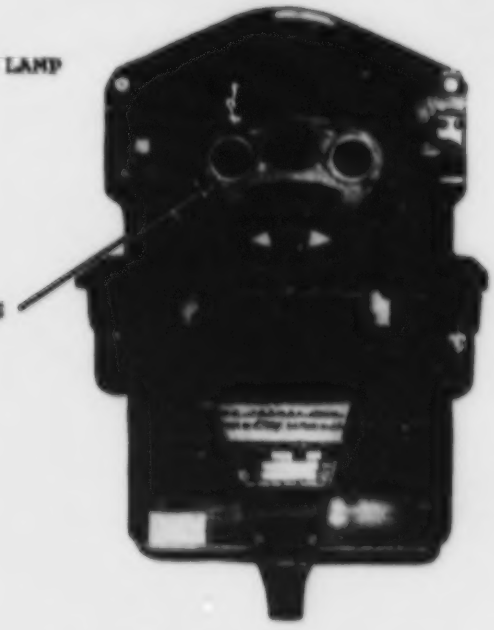


FIGURE 13b INNER ASSEMBLY

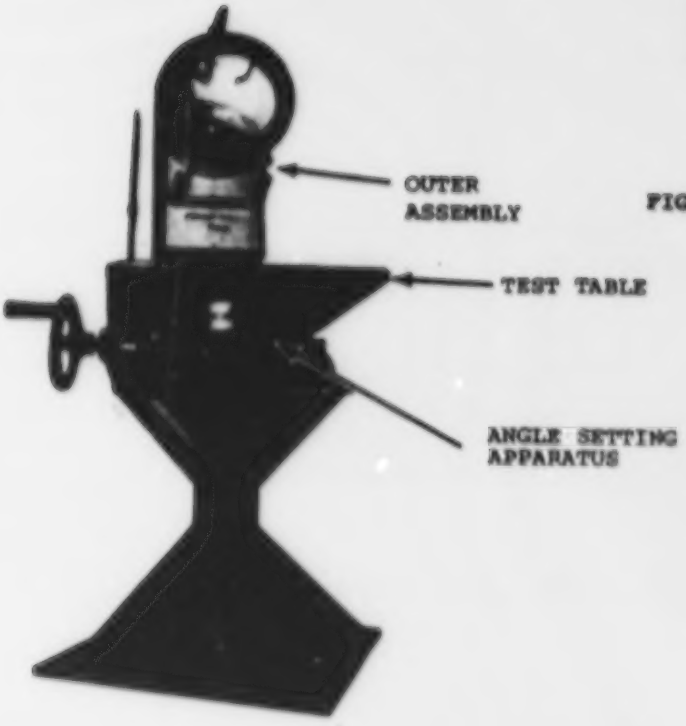


FIGURE 13c OUTER ASSEMBLY AND TEST TABLE

FIGURE 14a ARRAY SUPPORTING AND POSITIONING APPARATUS

FIGURE 14b ARRAY INSIDE EXISTING OUTER ASSEMBLY

ARRAY POSITIONING APPARATUS

6.0 EXISTING RAILWAY SEARCHLIGHT SIGNAL

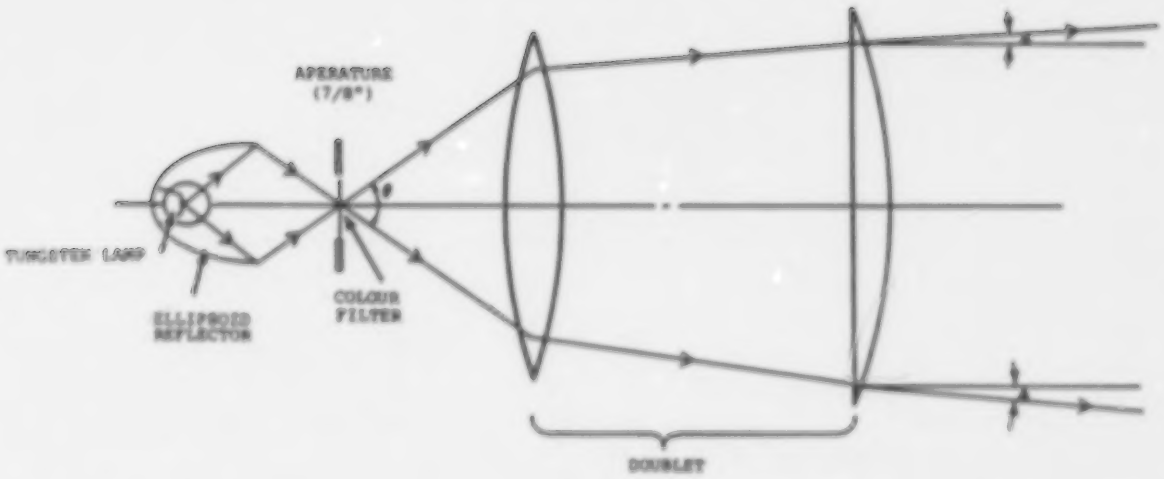
Most existing searchlight signals use a 10-volt, 18 Watt incandescent lamp with three focussing elements and three small colour filters. The optical geometry is illustrated in Figure 15. Surrounding the lamp is an elliptical reflector which focuses light through a 7/8 inch aperture containing a circular translucent coloured filter. The filter is electro-mechanically switched to allow any one of three colours to pass through to a doublet lens consisting of a 4 1/2" double convex lens with a 74° acceptance angle and a 8 3/8" plano-convex lens. The resultant light beam has a dispersion angle of roughly 2.5 degrees. (The dispersion angle is the angle of the light rays which are at 50% of the luminous intensity or the peak luminous intensity of the beam.) Figure 13a depicts the lamp and reflector sub-assembly while Figure 13b is a rear view of the rest of the inner assembly showing the arm containing the three coloured roundels. The outer housing appears in Figures 12, 13c and 14b.

6.1 CHARACTERIZATION

The existing signal light was characterized using the luminance profiling procedure described in section 5. Separate beam profiles were measured with each of the two meters for each of the three colours. The data from the Soligor meter is summarized in plot #1 (Page 68) and the Tektronix data is shown in plot #2 (Page 69). These plots bear out the observation that the yellow light has the highest luminance, as is to be expected from a Tungsten lamp. The beam angle at half of the peak luminance is about 2.5 degrees (by plot #2) for red and yellow but only 2 degrees for green. Plot #1 shows what appear to be wider beam widths but this is because the linear voltage scale shown is actually proportional to the logarithm of luminance.

The Soligor readings for red colours seemed to be enhanced compared to the Tektronix indicating that they don't have the

same colour response curve. The relative readings by either meter for different devices shining the same colour will still be valid, but at least one of the meters (looks like the Soligor) can't measure the relative luminance of different colours accurately.



θ IS THE ACCEPTANCE ANGLE OF THE LENSES (74°)

Δ IS ONE HALF OF THE BEAM DISPERSION ANGLE (2°)

FIGURE 15 EXISTING LENSES: OPTICS

7.0 CONCEPT 1 THEORY

Standard optical theory is well covered in Reference #1 and will not be repeated here. The assumption was made right from the proposal, that an array of LED's would be used to replace the existing lamp, for reliability reasons as well as brightness. This assumption, which turned out to be well founded, put the main thrust of optical design into finding techniques to force light from separate LED's to be concentrated in the desired 4° beam angle. Overlayed on this, was a desire to keep the design mechanically compatible with the original light.

One solution is to make the array small enough compared to the focusing lens to appear as a point souce, which can be surrounded with reflectors and lenses to focus all the light into a narrow beam. This technique runs into difficulty with size. For example: a 10 cm LED array would require at least a 60 cm lens about 3 meters from the array to produce a 4 degree beam. This assumes that the epoxy lens on each LED already concentrates the light into a 24 degree beam.

Early brainstorming produced 3 interesting techniques which had merit. Throughout this report these techniques are called concept 1, concept 2 and concept 3. All three of these concepts were investigated in parallel to try and determine which one best met the design constraints. Concept 1 is the idea of replacing the tungsten lamp, its ellipsoidal reflector and the colour filters with a LED array. Figure 16 shows a conceptual diagram. This may be compared to the existing arrangement shown conceptually in Figure 15. Light from the LED's passes through the aperture and is focussed by the doublet lens system. In order to maximize the amount of light passing through the aperture, all LED's in the array should be pointing directly at the aperture and close enough so that individual LED beams are not cut off by the aperture. Another restriction is that the light should enter and leave the aperture at less than the 74 degree acceptance cone of the doublet lens system. Light which passes through the aperture

will then be nearly collimated in a similar fashion to the existing light system. The easiest fabrication technique to meet the geometrical constraints is to mount the LED's on a spherical surface all pointing towards the center of the sphere. This allows each LED to be mounted naturally (perpendicular to the local surface) by seating the LED flange. A cross-sectional diagram of this arrangement is shown in Figure 18, and an exploded view of how the three assemblies fi together is shown in Figure 20.

7.1 METHODOLOGY

Work was channelled into concept 1 while waiting for deliveries of lenses and the positioning apparatus used in concepts 2 and 3. Several models were fabricated to test the validity of the concept. The first model consisted of only 2 LED's (pointing through the aperture) and proved that most of the light from both could be concentrated in the same beam. The second model (shown in figure 17a), consisted of a flat 4 x 4 array of HP red LED's. This array was used to investigate the imaging and optical path characteristics of both concept 1 and concept 2. The LED's could be pointed crudely by simply bending their leads. Shown in Figure 17b is the constant current driver schematic for model 2, which also included the ability to turn off half of the array

Models 4 through 6 all look similar to the devices shown in Figure 19a. The corresponding circuit (shown schematically in Figure 19b) allowed variation of the LED currents by using a variable voltage supply. The resistors in the circuit are acting as voltage to current converters or current limiters. The LED's were glued into a spherical surface all pointing towards the center of the sphere. Alignment of an array was accomplished via the 6 mounting and adjustment screws on the outer ring. The ring was machined to fit closely into the same cylindrical housing as the existing light bulb assembly (shown in Figures 13a, 13b, and 20). Model #3 contained 19 red HP LED's (an HP sample is shown in Figure 1). Model #4 contained 59 red HP LED's. Model #5 contained 19 red Stanely LED's and

Model #6 contained 39 Stanley red LED's (see Figure 19a). Although not at maximum packing density the LED's in Models 5 and 6 were packed closer together than those of earlier Models. The tapered shape of the Stanley red LED allows tighter packing in a concept 1 configuration as can be seen from Figures 18 and 21.

7.2 CONCEPT 1 - RESULTS

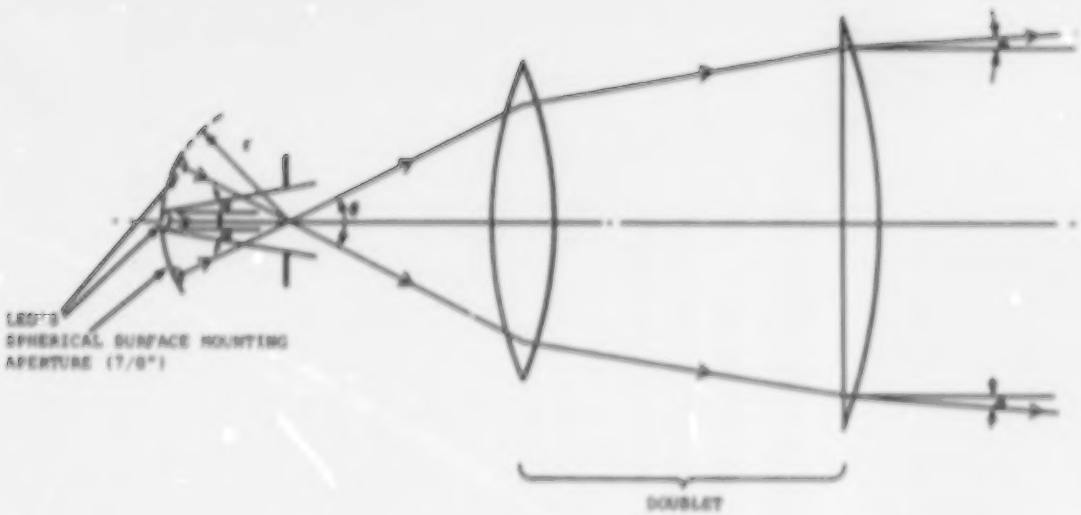
All of the concept 1 Models used red LED's and the emphasis was on improving the luminance performance of the array. Each successive array did improve in brightness but work on this concept tapered off before the brightness became comparable to the existing red light. Data for two concept 1 models is plotted in plot #3 with data from the existing red signal. An overlay of concept 1 results on concept 2a results is plotted in plot# 11 in Appendix A.

7.3 DISCUSSION

By comparison of the data in plot #3 it is apparent that the Stanley array was brighter than the HP array and that the existing light was brighter than either LED array. The beam angles appear wider than they actually are because of the logarithmic nature of the voltage measurement of luminance. A possible application for concept 1 is in mixing different LED colours. It is the preferred concept for mixing using a diffuser since the diffuser could be conveniently placed in the aperture or even switched in as the colour filters are switched now

The concept was not pushed to its luminance limits but it was explored far enough to determine that a 3 colour array at full beam luminance was not yet feasible. This determination was based on a combination of interrelated factors, such as: to improve brightness with current LED's means more LED's must be used; the size of the LED's limits how close they can be packed together so the array must grow at the edges; each LED

must be close enough to the aperture for most of its light to get through before its beam becomes too wide, and the arc of LED's should not exceed the 74 degree aceptance angle of the doublet; so as the array is expanded, more light is wasted. Making the aperture larger and changing the lenses might alleviate the problem but this would defeat the replacement philosophy of concept 1. It is probably feasible to make a full brightness red prototype, using the new Stanley H2000 LED's but any further work on this concept should probably wait for the other LED colours to improve in luminance.



r ADJUSTED SO THAT FOR AN LED OF A GIVEN α THE APERATURE IS FILLED

θ IS THE ACCEPTANCE ANGLE OF THE LENSES (74°)

α IS THE DISPERSION ANGLE OF THE LED'S

Δ IS ONE HALF OF THE BEAM DISPERSION ANGLE (24)

FIGURE 16 CONCEPT 1: OPTICS

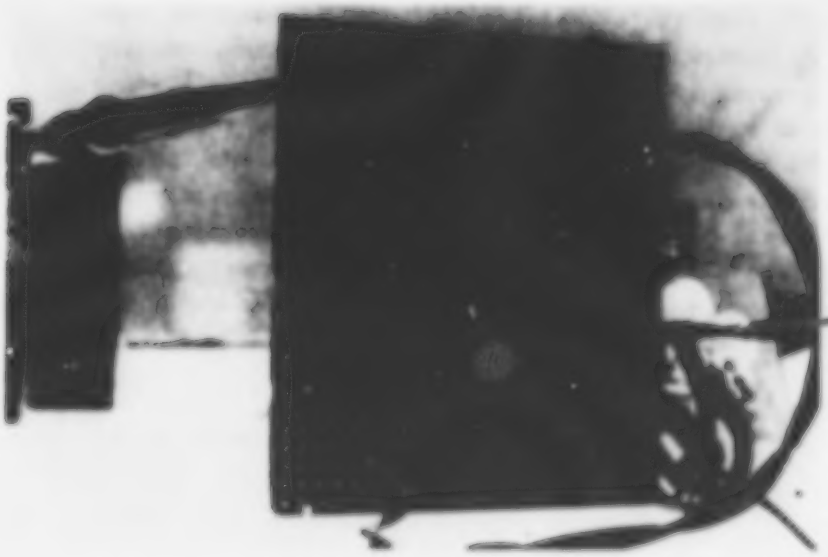


FIGURE 17a CONCEPT 1 & 2-2ND MODEL

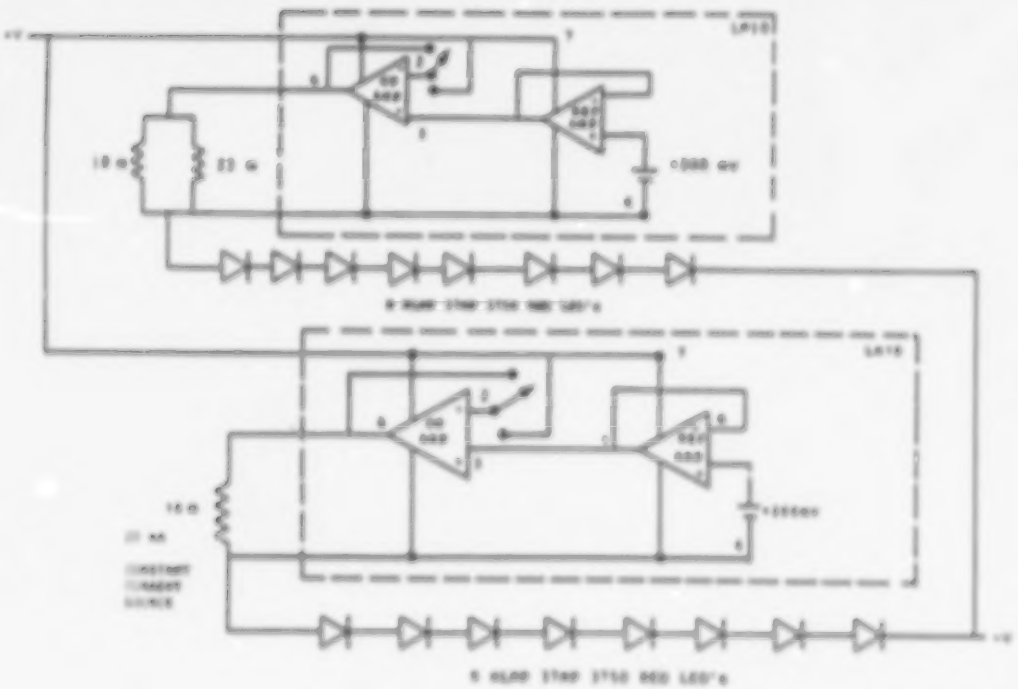


FIGURE 17b SCHEMATIC

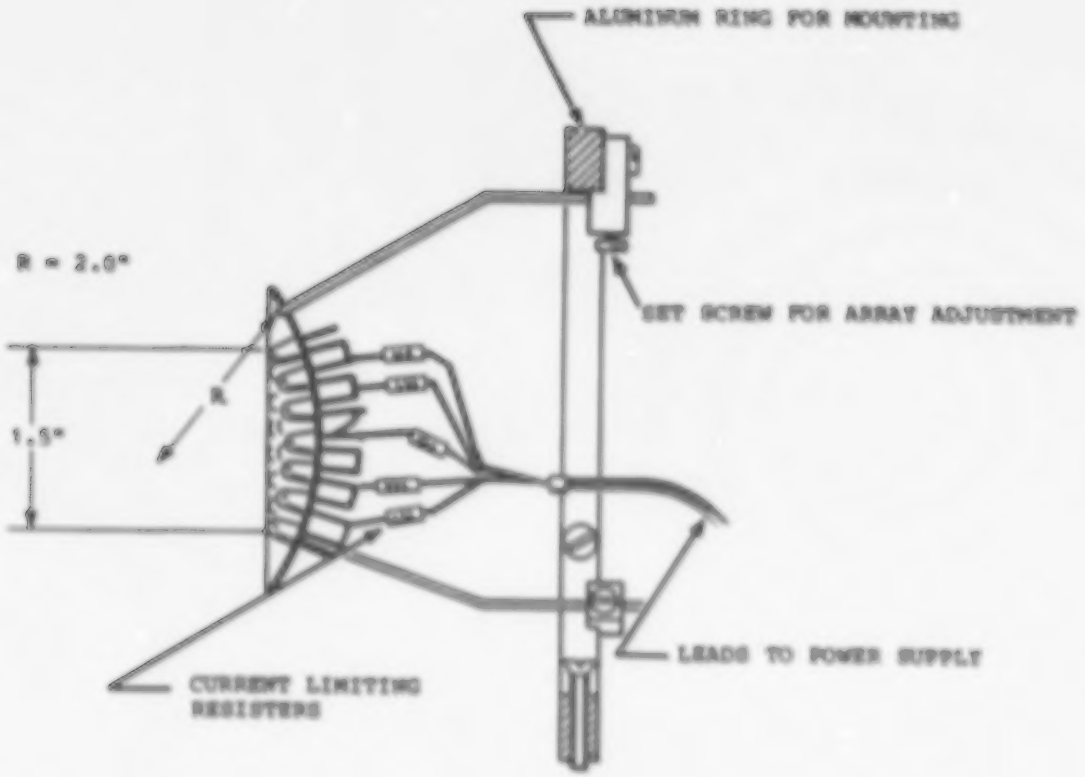


FIGURE 19 CONCEPT 1 6TH MODEL CROSS SECTION

FIGURE 19a CONCEPT 1 6TH MODEL
LAMP REPLACEMENT

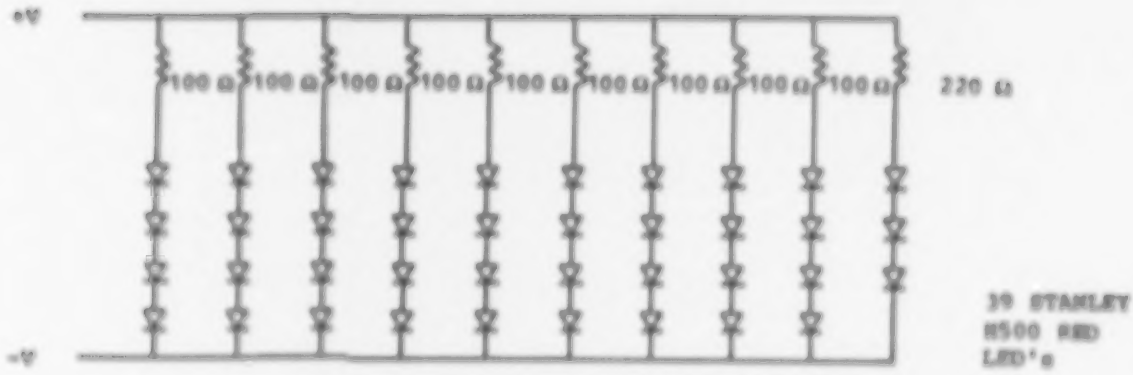


FIGURE 19b SCHEMATIC OF MODEL 6

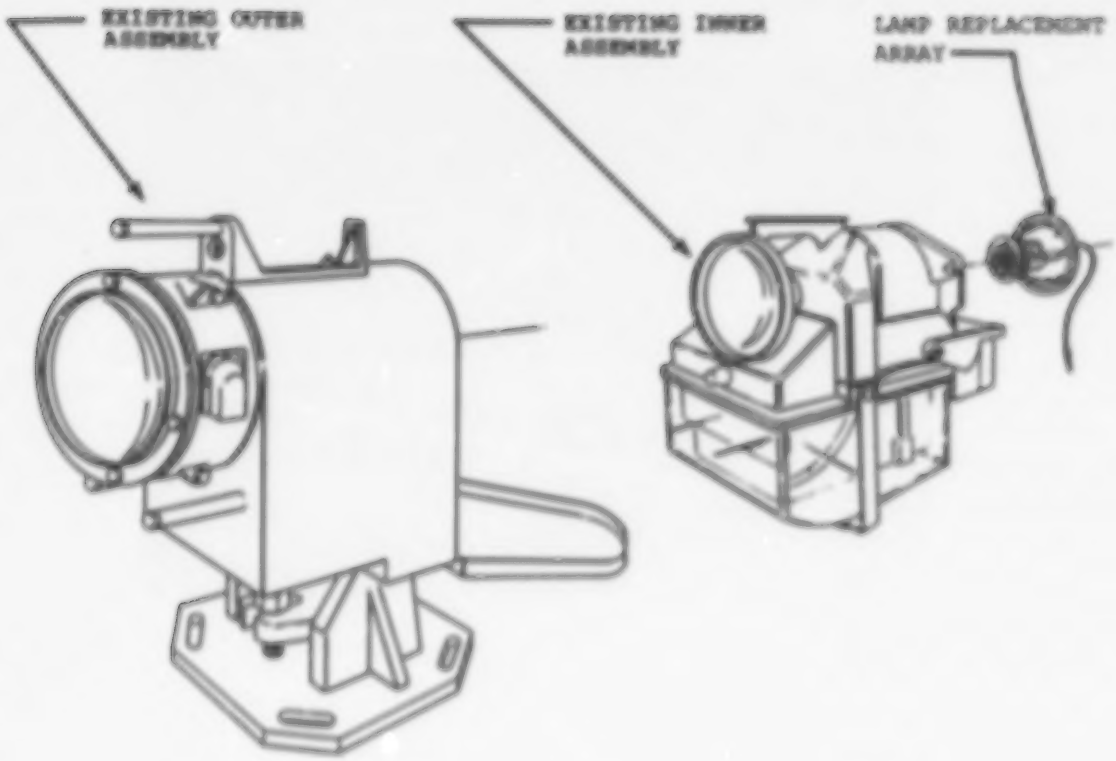


FIGURE 20 CONCEPT 1 GTE MODEL

FIGURE 21 HP VS STANLEY RED

8.0 CONCEPT 2

Concept 2 is a technique to replace the whole inner assembly of the existing light so that only the front lens is retained. This idea is shown conceptually in Figure 22. It treats the LED's as light rays so that by positioning and pointing them correctly it is possible to make all the LED rays look like they came from a point source or through a point source. Once the light has all been tied to a single point source, it can be handled with a traditional focusing lens. LED's do not produce single rays; consequently this concept tends to be degraded by off-axis light. If the LED array is near the focal point of the lens and far from the lens, then a wide beam from the LED is similar to a point source at the focal point, and can be focussed.

As in concept 1 the simplest implementation of concept 2 is to use a spherical mounting surface but with the LED's pointing away from the center of the sphere. If the sphere center coincides with the focal point of the lens then the light rays coming from the LED's will appear to come from the focal point or from somewhere nearby.

In a typical concept 2 case, an 8 inch front lens of focal length 12 inches and a 3 inch LED array on a spherical surface of radius 6 inches (centered on the front lens focal point), a 24 degree LED beam will be collimated to roughly a 4 degree beam. See Figure 22 and 25a. It should be pointed out that although all the light can be considered to come from a point source, and all the light winds up in the same beam, individual LED's are still discernable when looking at the light from 20 meters. This happens because the lens system doesn't mix or diffuse any light, it simply bends each ray until it points straight forward. A simple observation bears out the point; although each LED is pointed at a different angle inside, when looking at the array through the lens system, all LED's appear to be pointing straight forward.

Concept 2a is a modification of concept 2 making it one stage

more complex optically. This concept is illustrated in Figure 23 and shows a flat array of LED's shining through a concave lens before reaching the usual front lens. Adding a lens increases complexity but it enables a flat array of LED's to look like a diverging array, and a flat array is much easier to fabricate than a diverging or spherical array.

8.1 METHODOLOGY

The concept 2 models also started with just 2 HP red LED's (model #7) to test the technique. The second model (Figure 17a) was reused by bending the LED leads to obtain a divergent light pattern, but obtaining exact LED positions and angles proved difficult, especially when aligning the whole array in the signal housing by hand (the positioning apparatus arrived later when there were better arrays to test). The ninth model was fabricated from a plexiglass disk by machining 20 tapered holes around the edges. Each hole axis was angled out from the center at a 14 degree angle to make the light rays diverge. The hole tapers fit the tapers on the Stanley red LED's, which were then glued in position (see Figure 24a). This complex fabrication process was attempted to find out whether better LED alignment would significantly boost brightness. Extending the technique to a "filled area" array would have added unnecessary complexity. The driver circuit is shown in Figure 24b.

The tenth model was a spherical steel surface drilled with 59 holes. Stanley red LED's were glued into each hole with the LED angle being set by the LED flange seating against the steel. Figure 25a shows a picture of the 10th model along with 2 drawings to clarify the geometry and dimensions. Figure 25b is the corresponding circuit. The flange did not provide a very consistent orientation. This technique also had a problem with congested wiring, since all the LED leads were pointing in towards the center of the sphere.

In considering manufacturing techniques, it was decided that accurately positioning LED's radially in a spherical array was

not viable, so a variation of concept 2 was developed, called concept 2 A. The fundamental idea was to make a completely flat array of LED's, all pointing straight forward and use a lens to make the parallel rays diverge so that the front lens could collimate this "point source" as before. Model 8 was the first test of this technique. It consisted of 2 LED's mounted on a flat plate shining through a diverging lens behind the existing front lens. The 8th model's LED's are shown in figure 26a. The divergent lens is shown in figure 27, and the drive circuit in Figure 26b.

The 11th model was the first full array of three colours to be assembled. Based on concept 2A, and using a regular colour pattern, this model used the best LED's available at that time. Model 11 was fabricated from the components shown in the exploded illustration in Figure 28. A picture of the double concave lens is shown in Figure 27. The assembly with no lens is shown in Figure 29 and complete assembly is shown in Figure 33. Figures 14a and 14b show the unit in position to be tested. The schematic with its manual colour switching is shown in Figure 31. As illustrated by the plots in Figures 32a, b, and c the three colours were laid out in a symetrical pattern using almost equal numbers of LED's for each colour.

One final attempt was made to improve on model 11 and try a different LED colour pattern. Model 12 used LED's with their flanges removed for higher packing density and a slightly more orange "yellow" array. 124 LED's were squeezed into a smaller area than that occupied by the 85 LED's in model 11. Model 12 is shown in Figure 33 without lens and in Figure 34 with lens. The lens is shown in Figure 27 and the schematic is shown in Figure 35. The colour patterns are plotted in Figures 36a,b and c, showing the unequal numbers of each colour.

8.2 CONCEPT 2 - RESULTS

Model 9 worked well in concentrating the light into a beam but was easy to distinguish as a ring of LED's, even at fairly long range. It worked especially well with a beam spreading roundel which made it look much the same as a regular light. Luminance from the twenty LED's was less than models with larger numbers, as expected.

The luminance of model 10 was similar to the concept 1 arrays which encouraged the development of a three colour version. Concept 2a was selected for ease of production and to test the technique.

The size of the array was less restricted with concept 2 than with concept 1, because there was no constraint to make all the light pass through an aperture, however, there is an optimum size for efficiently concentrating the light into a 4 degree beam. The optimum size is related to the beam angle of the individual LED's (α). An approximate formula to calculate the optimum radius of a spherical array is given by $r=f(1-\tan[\alpha-\Delta]/\tan\alpha)$ where r is the radius, f is the focal length of the large lens, Δ is the lens dispersion angle. Notice as Δ approaches α the size of the array increases until it is as large as the front lens ($r=f$). The derivation is shown in Appendix A.

For a typical case, r is about 2 inches, but for a Stanley red LED the optimum radius increases to 6 inches. This greatly increases the number of LED's because their number is proportional to the spherical surface area which is proportional to r squared. It is not essential to use the optimum radius for two main reasons: 1) the function describing the increase in the number of LED's with increasing radius is roughly equal to the function describing the extra light loss due to increasing radius; 2) The light outside the 4 degree beam provides a wider beam, which is desireable.

The data from the eleventh and twelfth models are shown on plots 4-7. Plot #4 (Page 71) shows the Soligor readings for all three colours of model 11; Plot #5 (Page 72) shows the corresponding Tektronix data; Plot #6 (Page 73) shows Soligor data for model 12. The red array had the highest luminance in both arrays but model 12 used less luminous yellow LED's (but better colour), hence the yellow had higher luminance than green in model 11 and lower in model 12.

Comparing red plots of each model reveals that model 12 has a narrower beam angle (2.2°) than model 11, (2.5°) and higher luminanance. Note that the LED's in model 12 are packed closer together and the red LED's are grouped towards the center of the lens. See Figure 16a.

8.3 DISCUSSION

In comparing plots 2, 5 and 7 for the red case, it can be seen that the LED arrays are between one quarter and one eighth as bright as the existing light. This difference was not so noticable by eye or on plots using the Soligor meter (plots 1,4 and 6) because both of these work on a logarithmic scale for luminance. In the case of both models, if the red LED's were replaced by Stanley H20000 red LED's (now available), they would be at least as bright as the existing light.

Data from the two photometers was more difficult to interpret in the case of the other two colours. From both sets of plots, it is clear that beam spread for yellow and green is far too wide (the effect shows more clearly in the linear Tektronix plots). This imposes a peak luminance penalty on LEDs that are already less bright than the reds.

Further penalties were imposed in moving from model 11 to 12, because:

(a) we attempted to narrow the yellow LEDs by reshaping, which did not bring the expected gains.

(b) the yellow Hewlett-Packard LEDs were changed for National Semiconductor LEDs which were slightly more amber but had lower luminous intensity (see Table 3).

(c) probably of most significance, we attempted to incorporate patterns within the array, which placed yellow and green LEDs towards the periphery and caused additional light loss

Comparing ratios of peak luminance of the existing signal and model #11 or #12 for Soligor and Tektronix also reveals inconsistencies that may be due to differing spectral responses. This is a problem with any non-visual photometer; while it may be accurately connected to the standard eye response for broad spectrum sources, there can be relatively large errors over a narrow band. Since we are comparing a broad spectral source (filtered tungsten) to narrow spectrum LED sources, this may well be a problem.

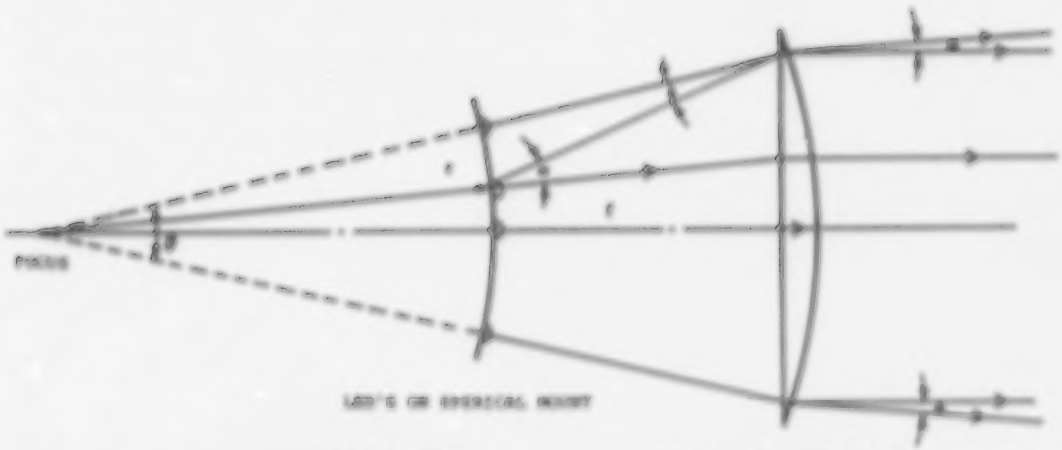
There are several strategies which can be pursued to improve performance:

1) use some of the work done on concept 3 to produce narrower angle LED's;

2) investigate light enhancement techniques described in Appendix C;

3) wait for or spur on new LED development.

It is obvious from the Tektronix data plots that the yellow and green LED beams are broader than 4 degrees, so strategy 1 would concentrate more light into the beam and at the same time, allow more LED's to be put in the array. Strategy 2 may provide some help but will reduce effeciency. Strategy 3 has various levels of involvment but should be followed up at least to the point of publishing the railway requirements and sending copies to the various manufacturers.



α IS THE ACCEPTANCE ANGLE OF THE OBJECTIVE LENS (15.5°)

γ IS THE DISPERSION ANGLE OF THE LED'S

Δ IS LEDS HALF OF THE BEAM DISPERSION ANGLE (2°)

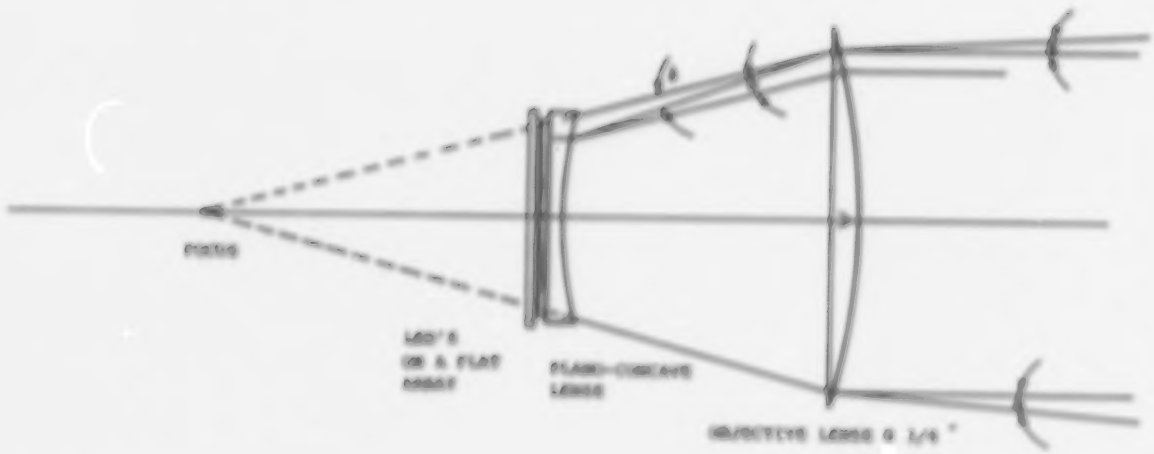
f IS THE FOCAL LENGTH OF THE OBJECTIVE LENS 12"

$$\Delta = \delta = \alpha = \tan^{-1}\left(\frac{f+x}{x}\tan\alpha\right)$$

$$x = f\left[1 - \frac{\tan(\gamma+\Delta)}{\tan\alpha}\right]$$

x IS THE DISTANCE FROM THE FOCUS TO ANY LED

FIGURE 22 CONCEPT 1: OPTICS



θ IS THE DISPERSION ANGLE OF THE LED'S
δ IS ONE HALF OF THE COLLIMATED BEAM ANGLE (2°)
f IS THE FOCAL LENGTH OF THE OBJECTIVE LENS

FIGURE 23 CONCEPT 2A: OPTICS

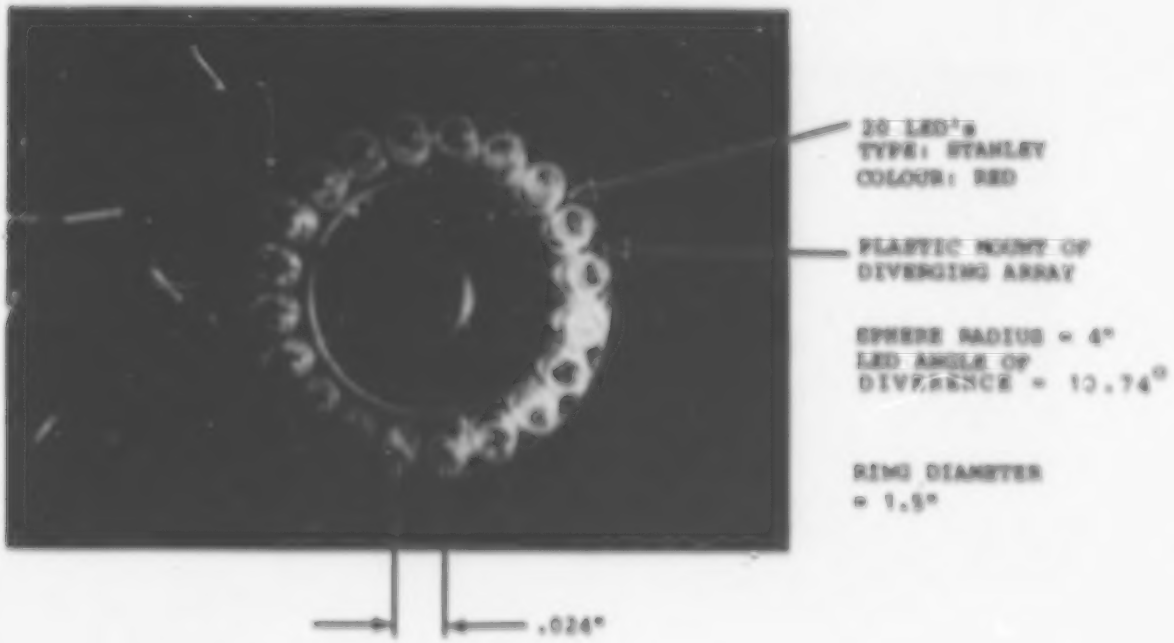


FIGURE 24a CONCEPT 2 9TH MODEL

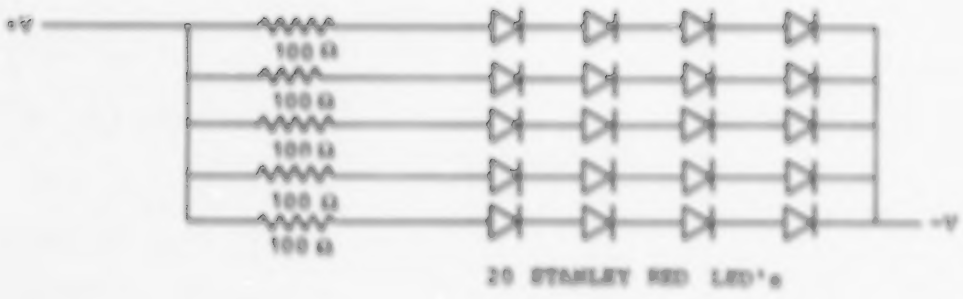


FIGURE 24b SCHEMATIC OF 9TH MODEL

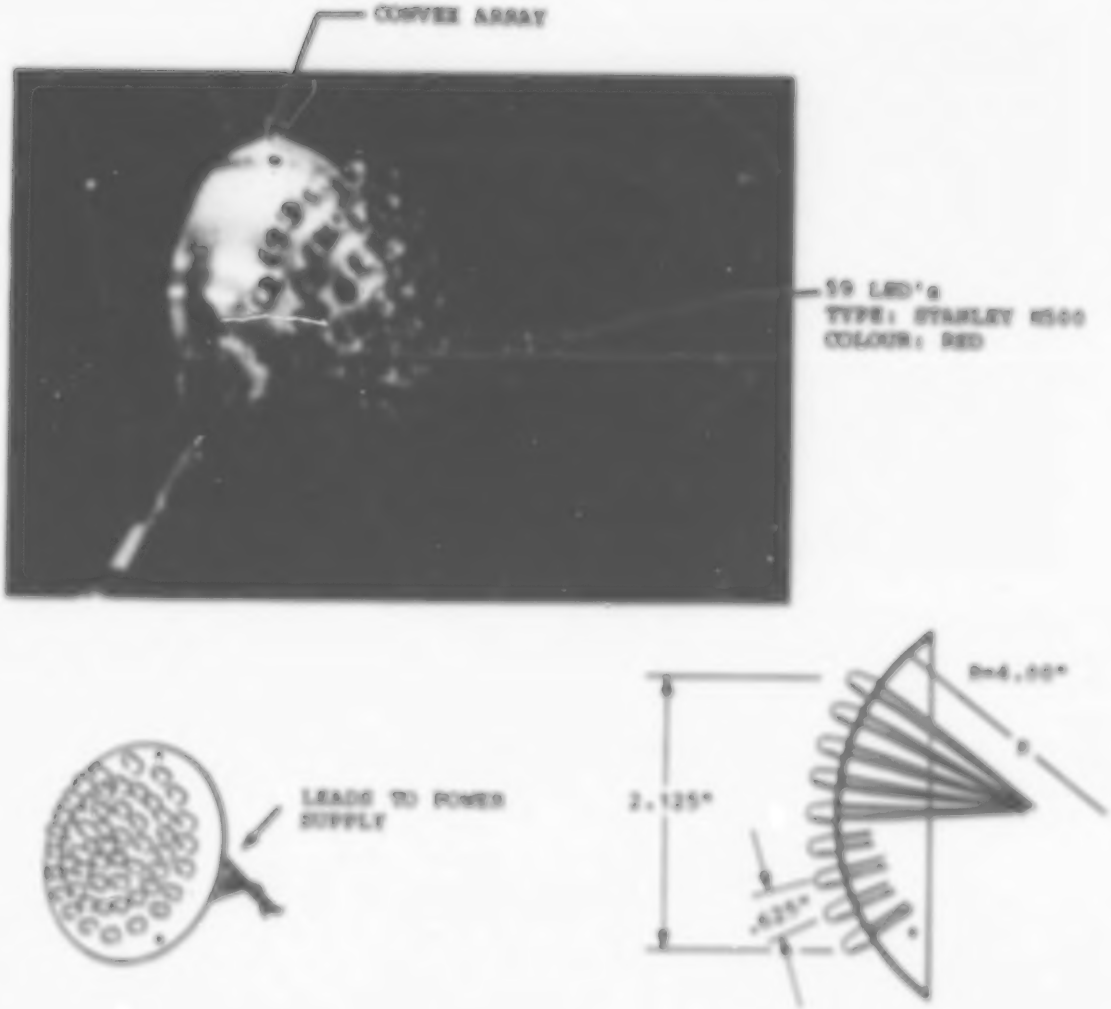


FIGURE 25a CONCEPT & 1978 MODEL

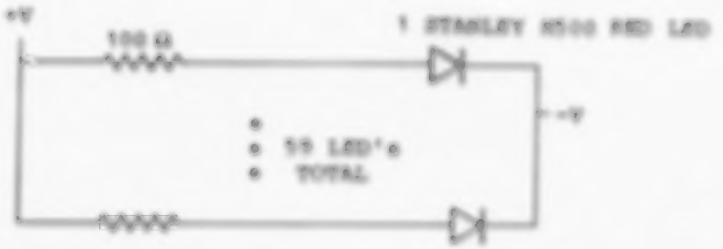
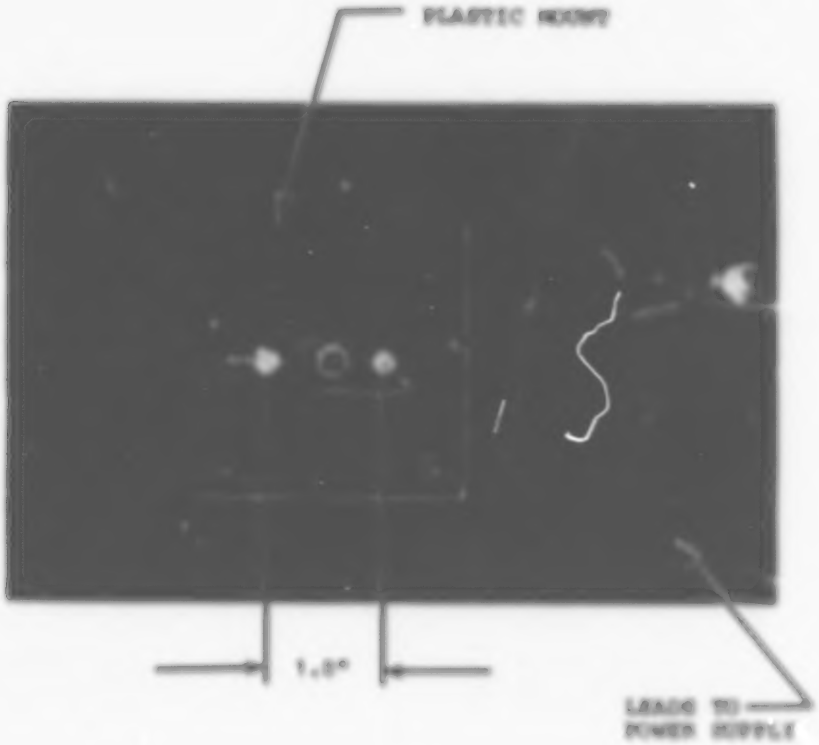


FIGURE 25b SCHEMATIC OF 1978 MODEL



LED's
TYPE: STANLEY
COLOUR: RED

FLAT MOUNTING
USED WITH A
DIFFUSEMENT LENS

FIGURE 24a CONCEPT IA GYR MODEL

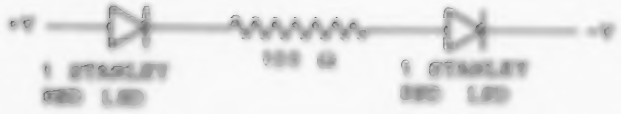


FIGURE 24b SCHEMATIC OF MODEL 8

FIGURE 27 LENSES FOR CONCEPT 2A MODELS 8,11 AND 12

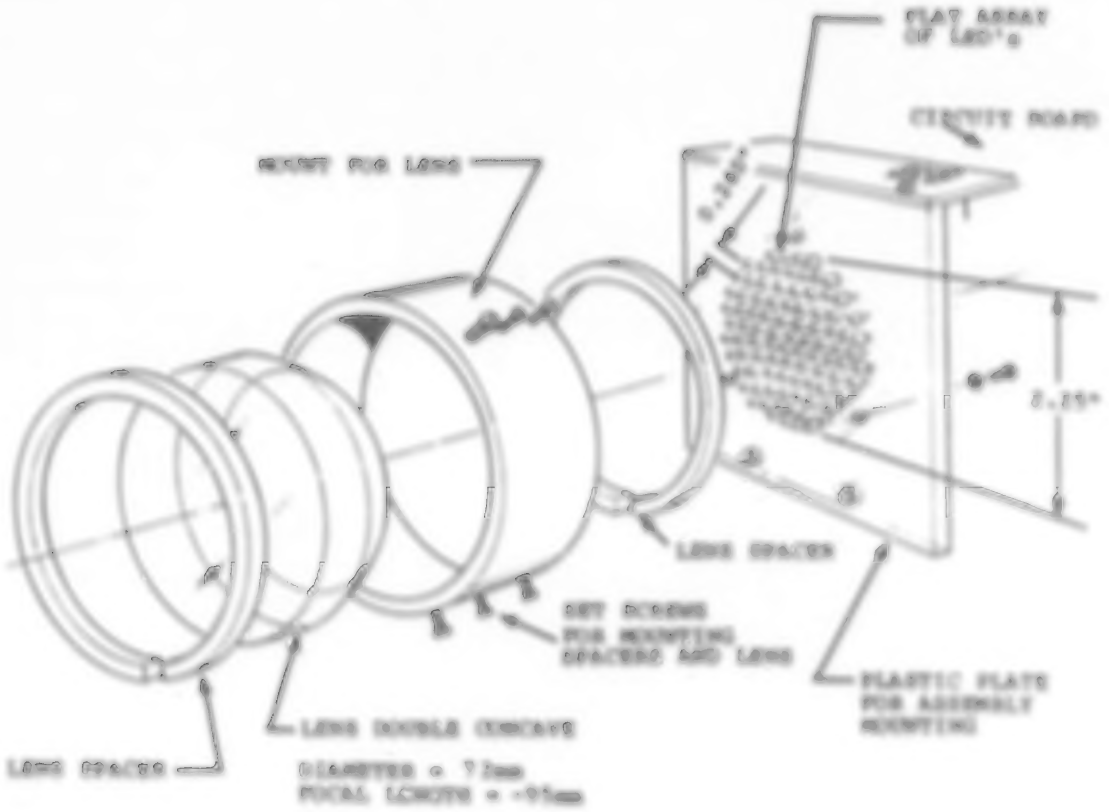
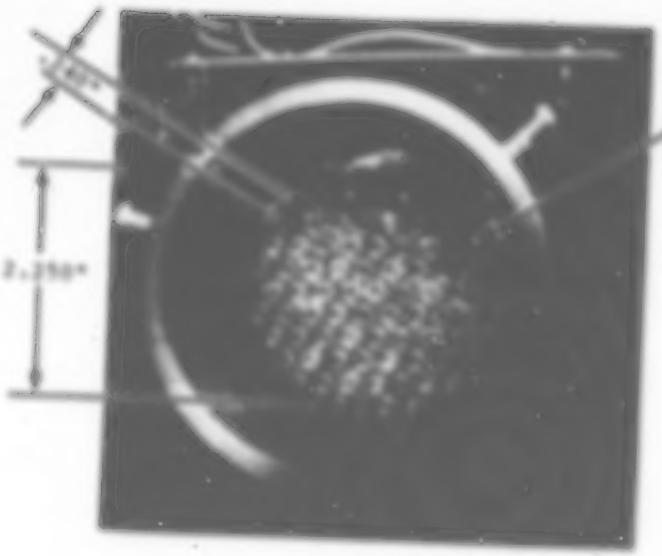
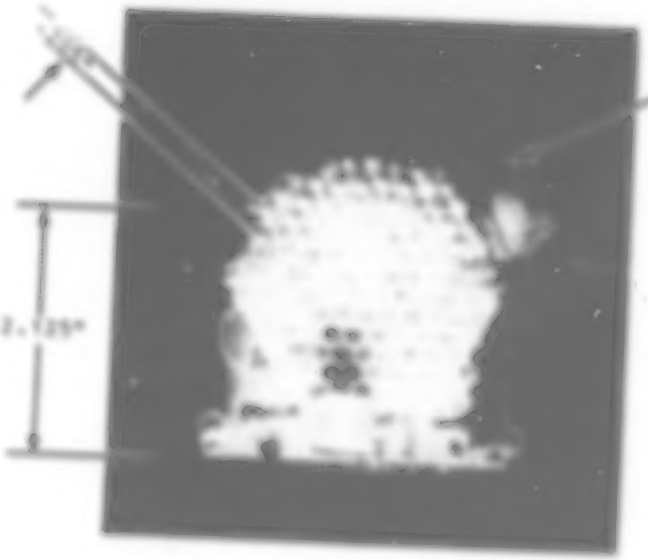


FIGURE 20 CONCEPT 2A LENS PROTOTYPE



#	COLORS	TYPE
31	RED	STANLEY 4500
27	GREEN	DATA DISPLAY
27	YELLOW	HEWLETT-PACKARD

FIGURE 29 CONCEPT 2A 1170 MODEL - 80 LEDS



#	COLORS	TYPE
29	RED	STANLEY
50	GREEN	DATA DISPLAY
45	YELLOW	NATIONAL

FIGURE 30 CONCEPT 2A 1170 MODEL

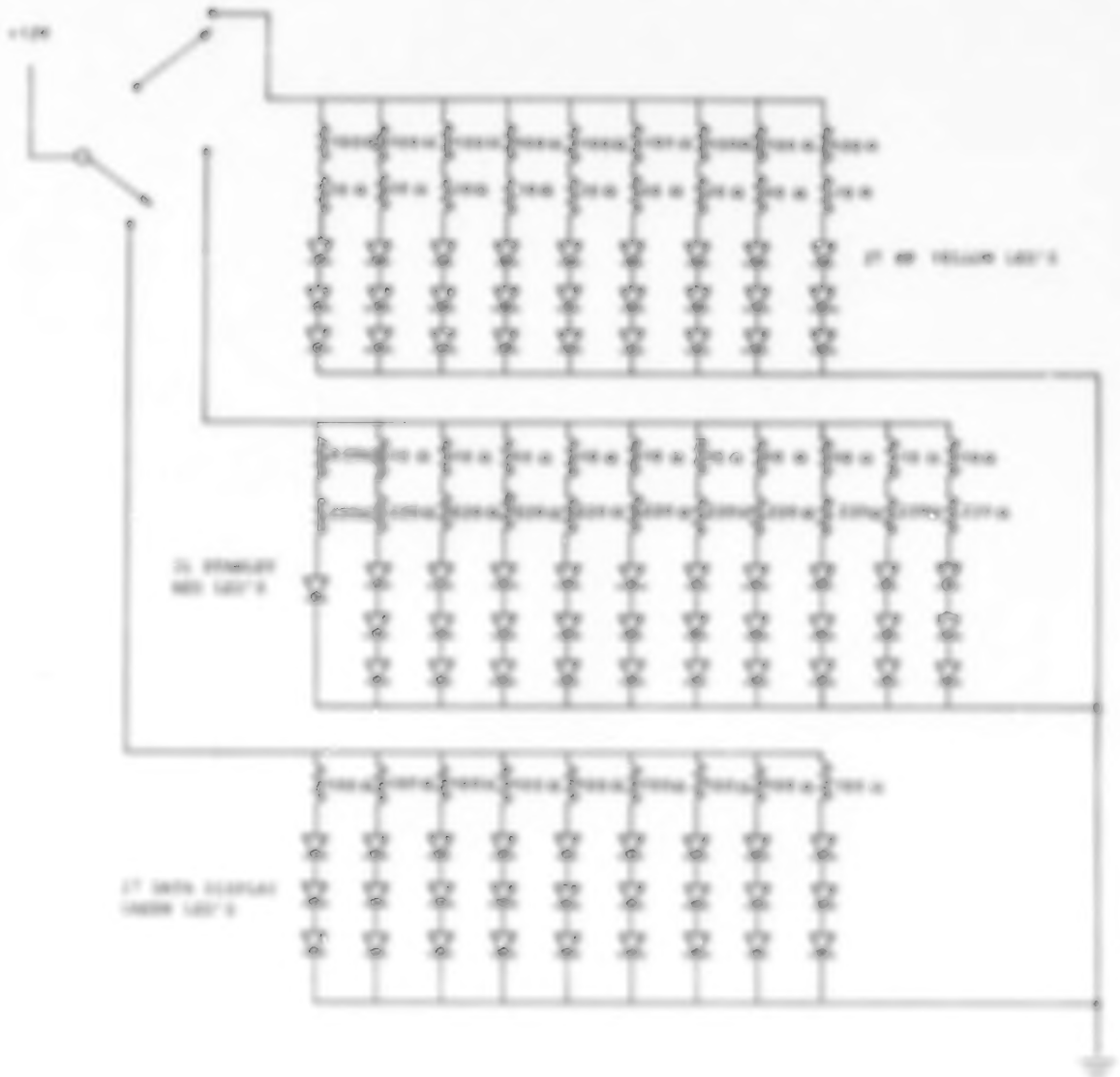
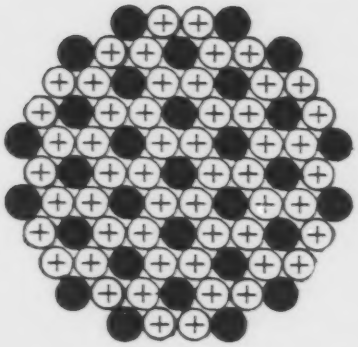


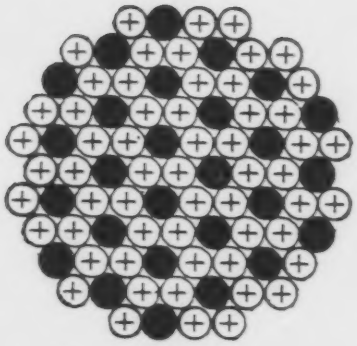
FIGURE 31 CIRCUIT 2A TYPE MODEL SCHEMATIC

FIGURE 32a



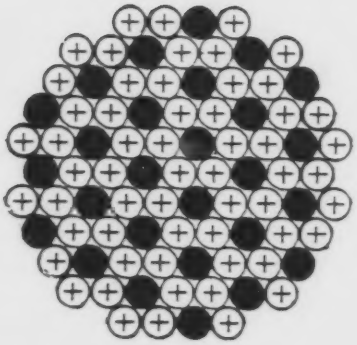
RED

FIGURE 32b



YELLOW

FIGURE 32c



GREEN

● - ILLUMINATED
⊕ - NOT ILLUMINATED

CONCEPT 2A 11TH MODEL COLOUR PATTERN

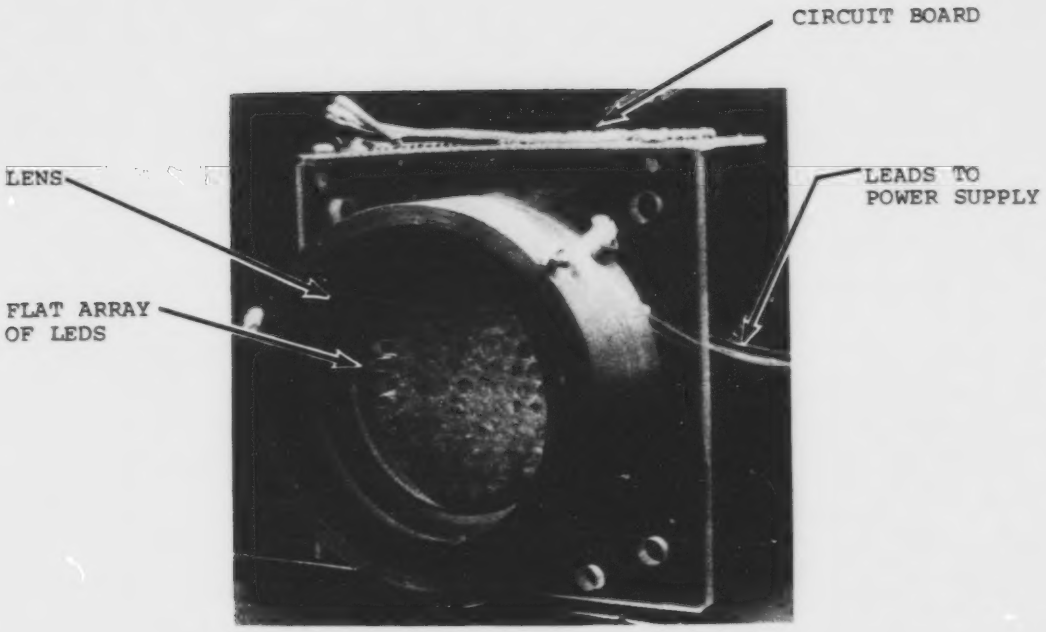


FIGURE 33 CONCEPT 2A 12TH MODEL - NO LENS

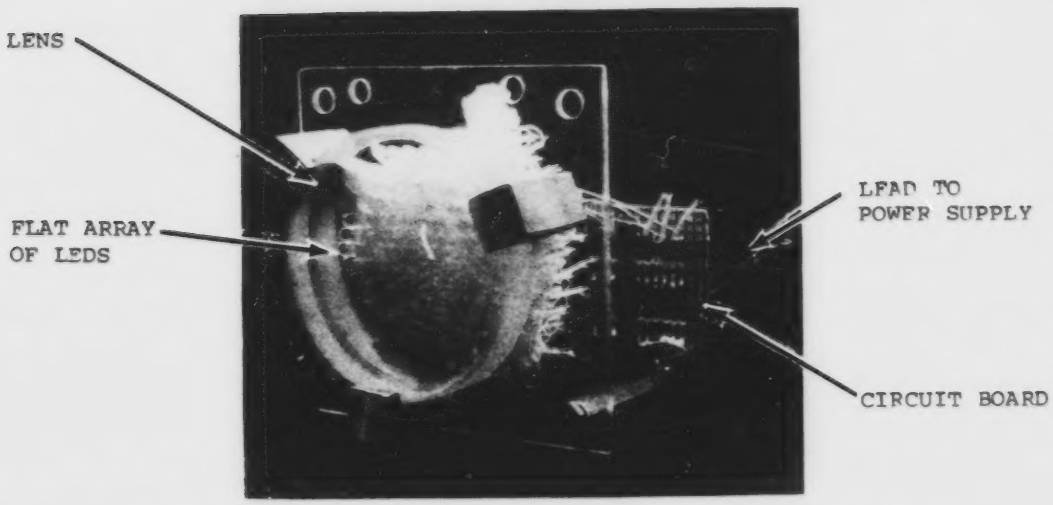


FIGURE 34 CONCEPT 2A 12TH MODEL

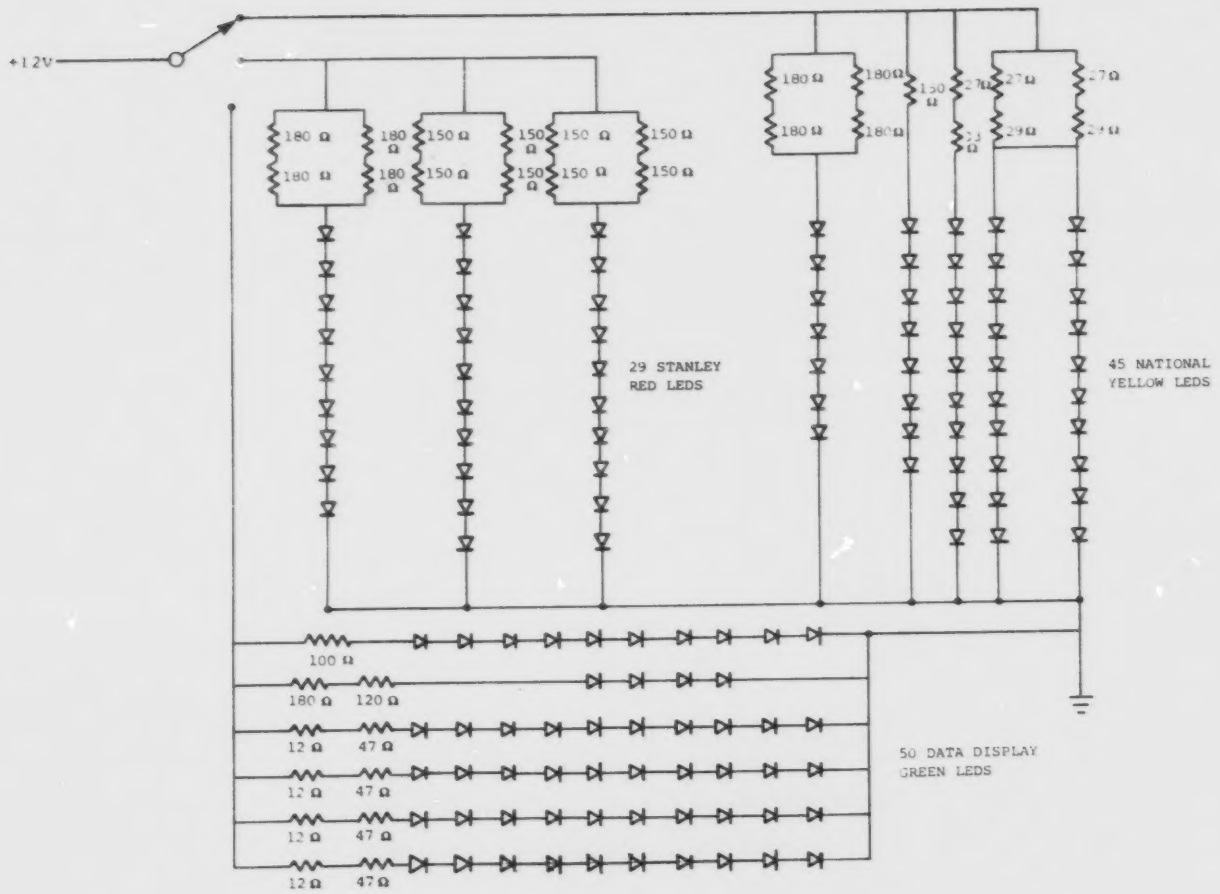
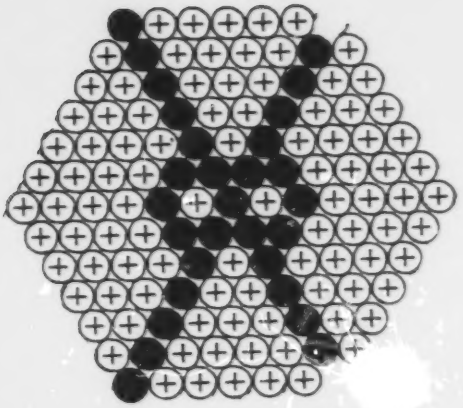


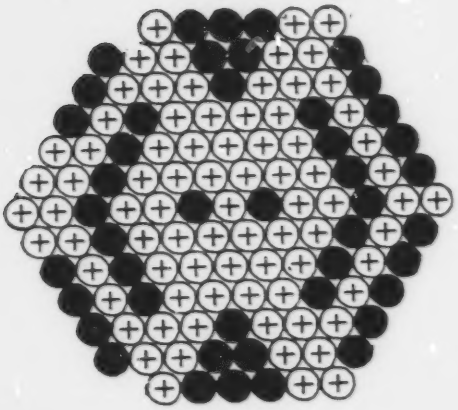
FIGURE 35 CONCEPT 2A 12TH MODEL SCHEMATIC

FIGURE 36a



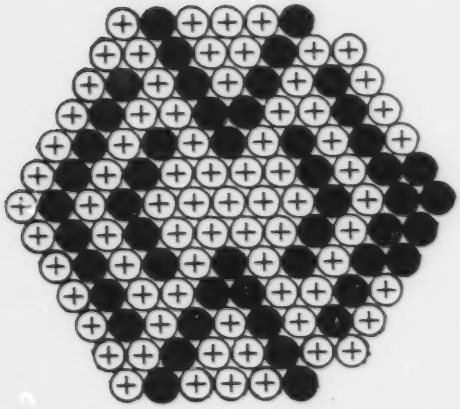
RED

FIGURE 36b



YELLOW

FIGURE 36c

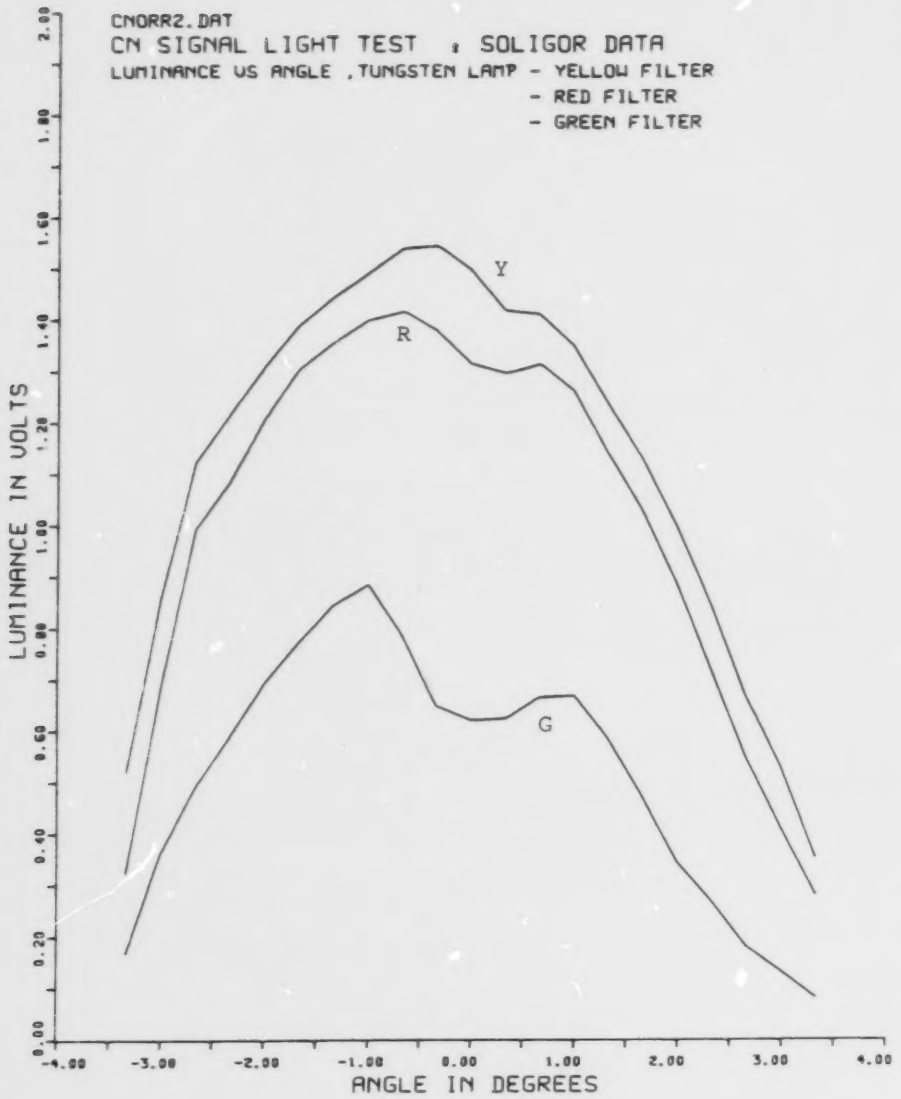


GREEN

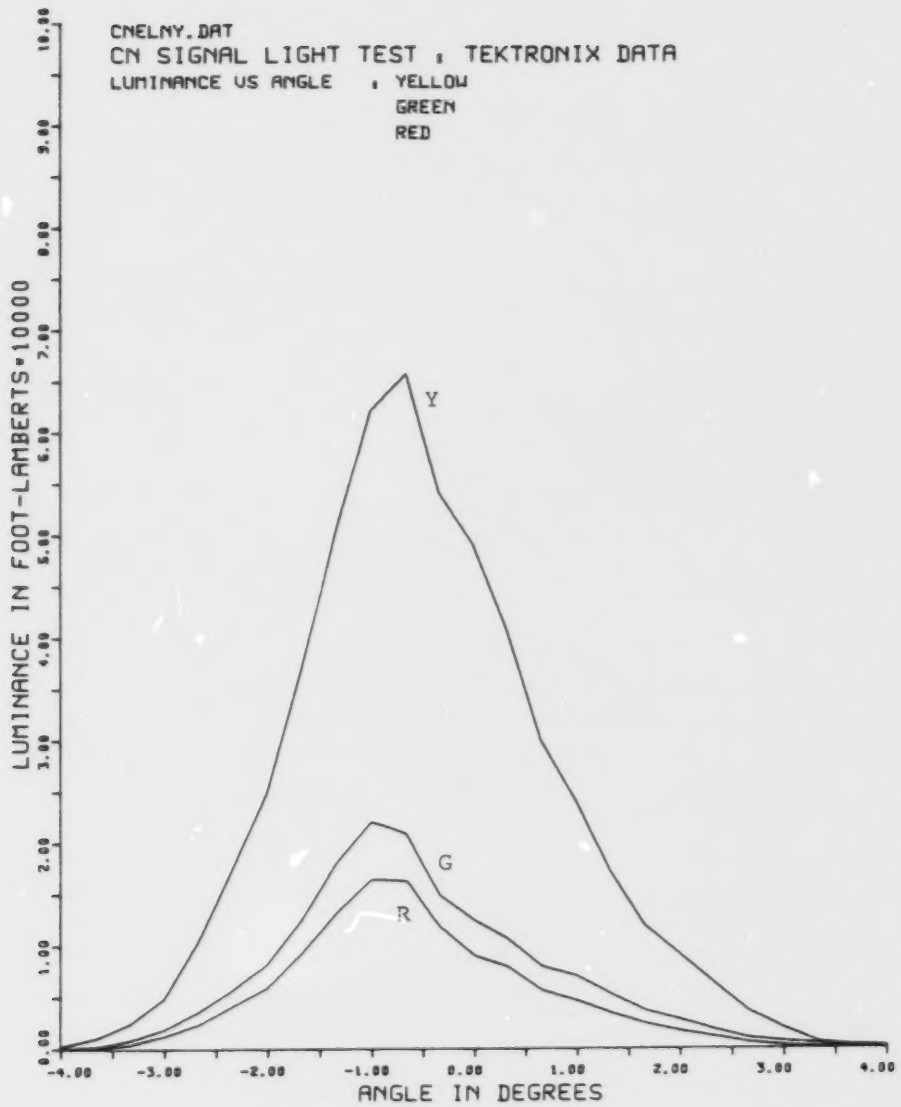
● - ON

⊕ - OFF

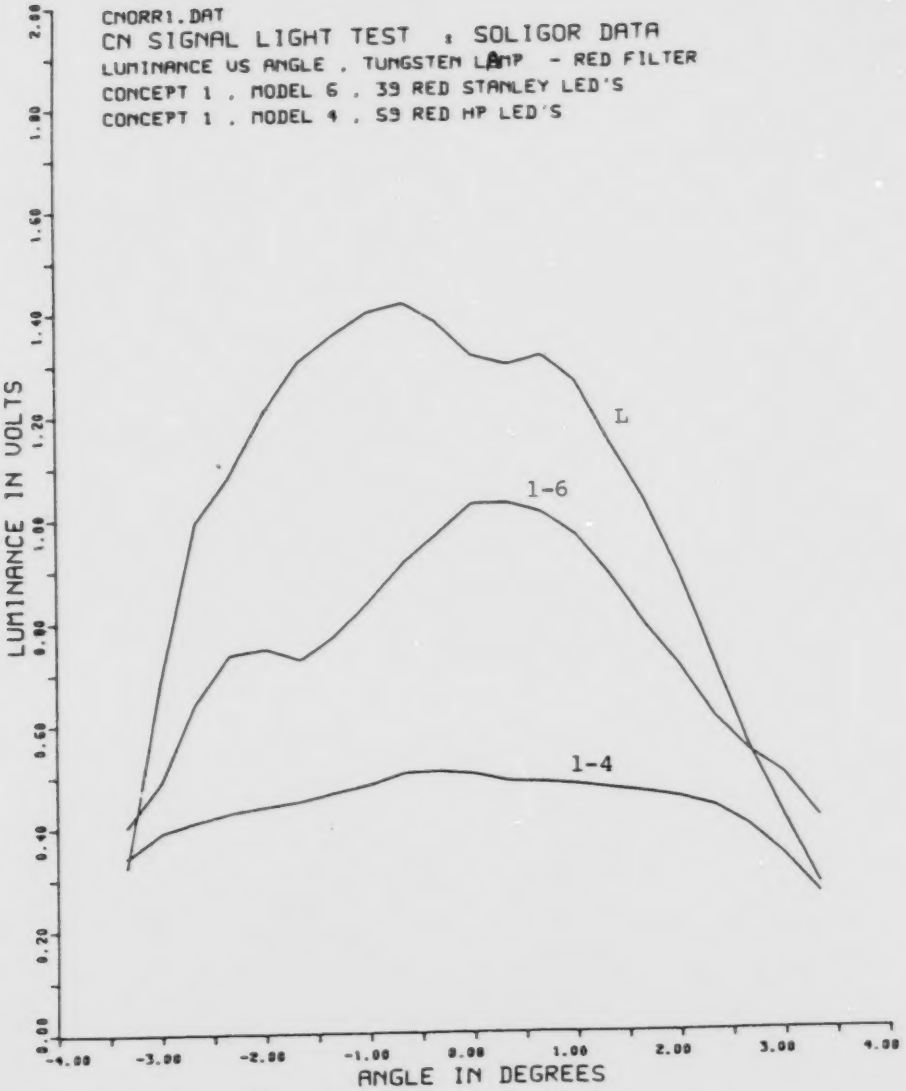
CONCEPT 2A 12TH MODEL COLOUR PATTERN


CNORR2.DAT
CN SIGNAL LIGHT TEST : SOLIGOR DATA
LUMINANCE VS ANGLE ,TUNGSTEN LAMP - YELLOW FILTER
- RED FILTER
- GREEN FILTER
Y
R
G
LUMINANCE IN VOLTS
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
ANGLE IN DEGREES

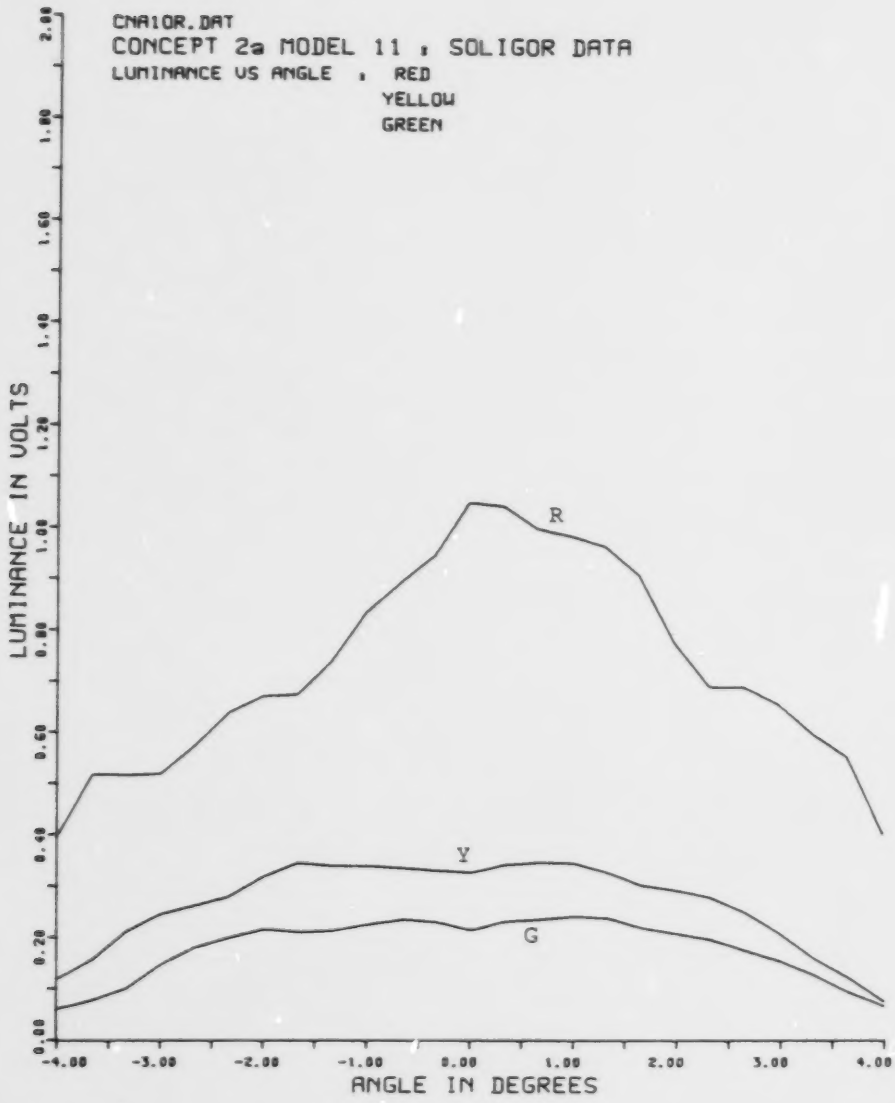
PLOT #1


CNELNY.DAT
CN SIGNAL LIGHT TEST : TEKTRONIX DATA
LUMINANCE VS ANGLE : YELLOW
GREEN
RED
LUMINANCE IN FOOT-LAMBERTS*10000
ANGLE IN DEGREES
Y
G
R
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00

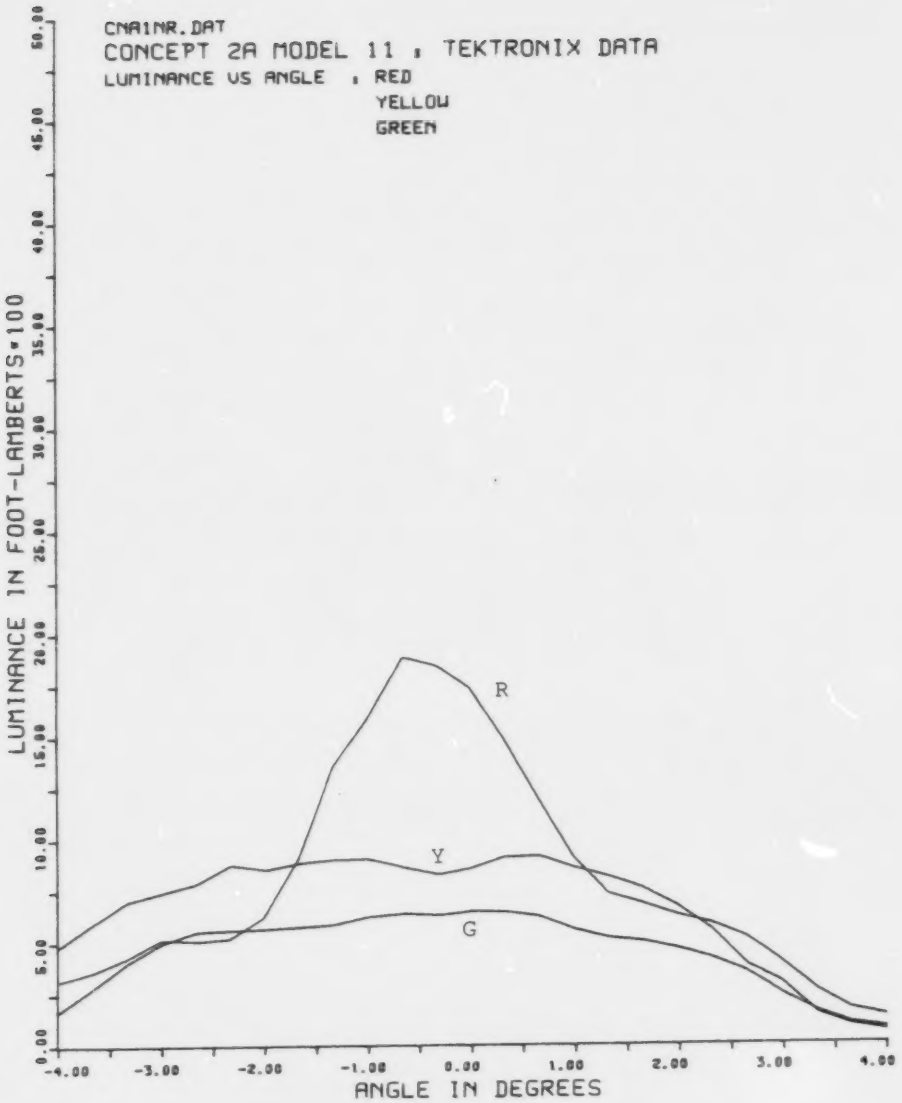
PLOT #2


CNORR1.DAT
CN SIGNAL LIGHT TEST : SOLIGOR DATA
LUMINANCE VS ANGLE . TUNGSTEN LAMP - RED FILTER
CONCEPT 1 . MODEL 6 . 39 RED STANLEY LED'S
CONCEPT 1 . MODEL 4 . 59 RED HP LED'S
LUMINANCE IN VOLTS
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
L
1-6
1-4
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
ANGLE IN DEGREES

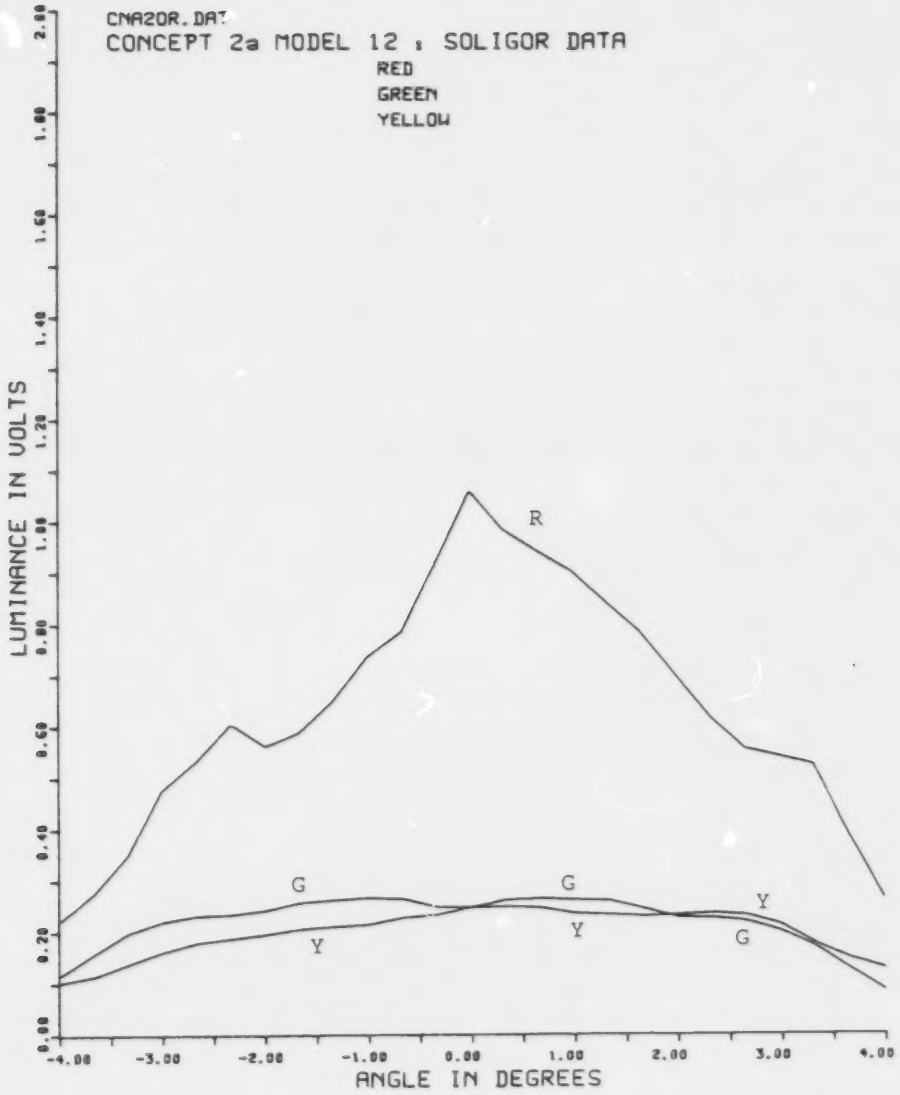
PLOT #3


CNA1OR.DAT
CONCEPT 2a MODEL 11 ; SOLIGOR DATA
LUMINANCE VS ANGLE , RED
YELLOW
GREEN
LUMINANCE IN VOLTS
ANGLE IN DEGREES
R
Y
G
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00

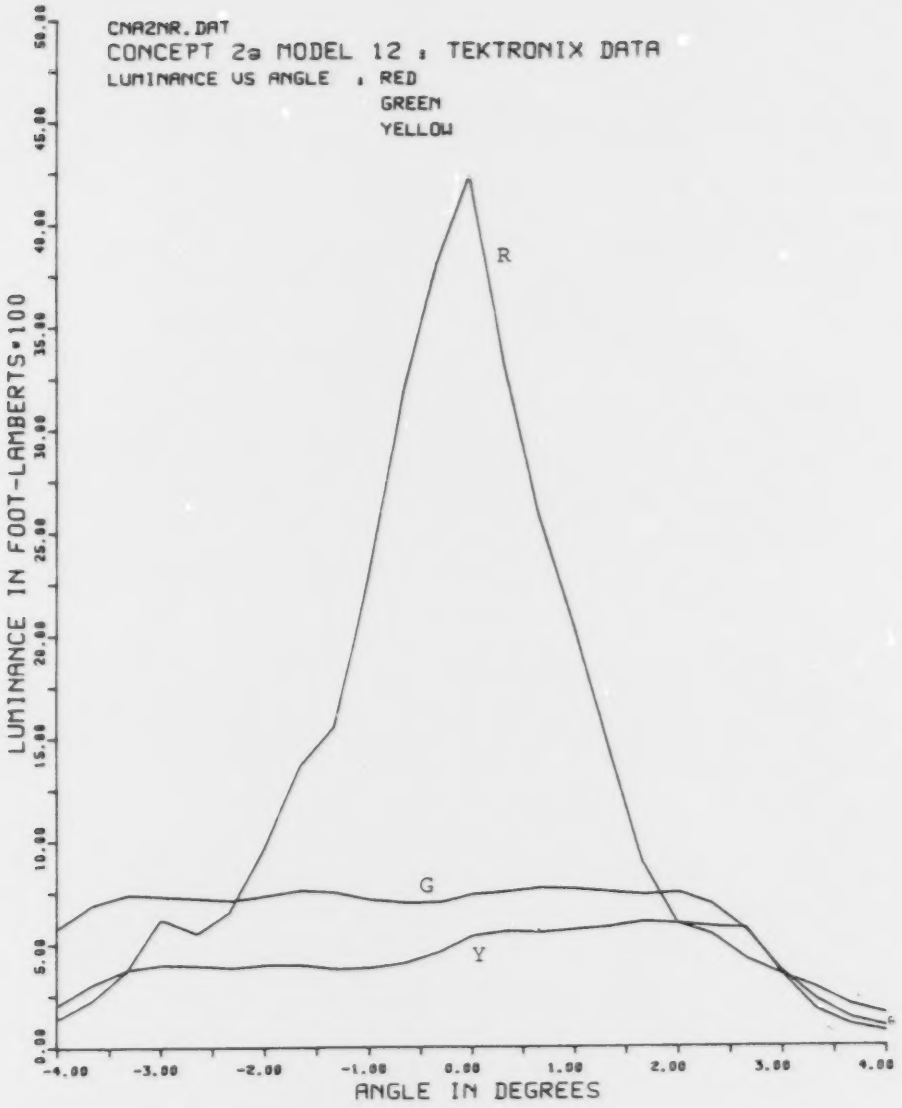
PLOT #4


CNA1NR.DAT
CONCEPT 2A MODEL 11 ; TEKTRONIX DATA
LUMINANCE VS ANGLE ; RED
YELLOW
GREEN
LUMINANCE IN FOOT-LAMBERTS*100
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
R
Y
G
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
ANGLE IN DEGREES

PLOT #5


CNA2OR.DAT
CONCEPT 2a MODEL 12 : SOLIGOR DATA
RED
GREEN
YELLOW
LUMINANCE IN VOLTS
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
R
G
G
Y
Y
Y
G
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
ANGLE IN DEGREES

PLOT #6


CNA2NR.DAT
CONCEPT 2a MODEL 12 : TEKTRONIX DATA
LUMINANCE VS ANGLE : RED
GREEN
YELLOW
LUMINANCE IN FOOT-LAMBERTS*100
ANGLE IN DEGREES
R
G
Y
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00

PLOT #7

9.0 CONCEPT 3

If the lens on each LED could concentrate the light from that LED into a 4 degree beam, there would be no necessity for a large lens and in fact there would be no need for the array to look like a point source. At a distance far enough away that the array did look like a point, the composite light beam would have a dispersion angle of 4 degrees. This technique was labelled concept 3 throughout the investigation and this report. The lens may be external to the LED as shown in the conceptual diagram in Figure 37a or part of the LED as shown in Figure 37b.

Another way to increase the brightness in the 4 degree beam, is to simply add LED's to an array with no lens, and let the light outside the 4 degree beam disperse, without trying to collect or focus it. This technique has the added benefit of a wider beam but but wastes typically over 90% of the available light. Power constraints limit the number of LED's to about 150, so several well focused LED's would be just as good in the narrow beam of interest. Appendix A contains plots of luminance for single LED's.

9.1 METHODOLOGY

Concept 3 was the last technique to obtain significant results due to the difficulty of obtaining appropriate lenses. Initially the lenses of the various LED's were compared to find out why some were better than others. This led to several attempts to modify poorer lenses to produce narrower beams. See Figure 38 and 39 for some standard lens geometries and Figure 41 for typical modifications. Note the taper and the smaller radius of the modified lens. The narrowest angle LED's available were a discontinued line from Fairchild but these could not be copied by machining because their lenses were larger than any of the others. See Figures 38 and 39. A selection of small glass lenses were ordered and many short tests were performed to see how much light could be collimated

and how small the lens could be made. Typical models are shown in figures 42a,b and c. Figure 42a shows a normal LED with a machined plexiglass collar which keeps the LED straight as it is inserted in the brass tubes shown in Figure 42c. The brass tube has a glass bi-convex lens glued to its front and the LED is focussed by sliding it in the tube. Figure 42b shows a modified LED also with a plexiglass collar. The top of this LED was polished flat to see if the glass lens alone could focus the light.

Model #16 was the first attempt at an array using concept 3. It was made by sandwiching seven lenses between two predrilled aluminum plates as shown in figure 43a. The seven LED's were mounted on a printed circuit board behind the lenses. This arrangement was extremely difficult to align becasue there was no provision for lens tilting and LED's had to be pointed and positioned by bending leads. The circuit is shown in Figure 44a. Another attempt was made to make this technique work using Stanley LED's (model #17) but the same problems prevented it from being successful enough to take quantitative measurements. The beam viewers were used to determine that the beam was not collimated well. The array is shown in Figure 43b without lenses and its corresponding circuit in Figure 44b.

The general requirements for an optimum external lens are that the focal length be about 2 diameters and the diameter large enough for the LED to appear as a 2 degree point source. Since these constraints imply large lenses, it follows that small lenses waste some light. Tests were conducted to verify that a significant portion of the available light was wasted. The drawback to large lenses is that they take up too much room to enable large arrays of lenses. After these tests, the work on concept 3 was concentrated on designing and fabricating the optimum lens as part of a LED. This technique allows much smaller lenses, because the point source is smaller and there is no need to use a lens with a spherical surface. The source here is considered to be the area of the metallic bowl reflector around the actual LED chip, as opposed to the frontal area of a standard LED lens.

A Fortran program was developed to calculate optimal lenses for any desired beam dispersion angle and any source size and to plot full scale profiles complete with all relevant dimensions. See Appendix A for some examples. The program is in Appendix D. These plots were used as templates in making lathe tools to turn out nearly ideal lenses. (The ideal situation would be to have an ellipsoidal lens mould as part of the LED fabrication process, instead of the standard spherical mould.) To couple the LED's to the prototype lenses, the epoxy LED lenses had to be cut off flat, just above the LED chip and polished before being glued to the plexiglass lenses. The differences in the relative indicies of refraction of the epoxy lens, the glue and the plexiglass lens should affect the lens calculation but all indicies of refraction were just assumed to be 1.52. This is an approximation based on the fact that most plastics are very close to this value. Alignment of LED and lens turned out to be a close tolerance operation and could not be accomplished perfectly by hand even with the LED turned on. Some kind of jig is necessary.

An initial lens was made up to prove that an ellipsoidal lens could collimate light and then two more were fabricated to see if the three light beams would add up to produce a single beam three times as bright. The triple lens array was model 26 and is shown in Figure 45a. Figure 45b shows a plot of the lens profile as calculated by the program in Appendix D. This program calculates a perfectly collimating lens shape based on a point source and then makes it large enough so that the angle that the source subtends from the lens surface is equal to the desired dispersion angle. This means that the dispersion angle is due to the non-idealness of the source as a point of light.

9.2 CONCEPT 3 - RESULTS

LED modification on a lathe was used to turn an HP LED roughly into the shape of a Stanley H500. See figures 21 and 41. As can be seen, the lens surface was not highly polished after the reshaping, but, although some light was lost, the beam width was cut in half. This technique was used on the yellow LED's

in model 12, but their light output was reduced.

External lens testing like that shown in figure 42 determined that the light which reached the lens could be focussed or collimated better as the lens diameter was increased because the LED became relatively more like a point source. More light was collected and collimated from standard LED's than any kind of modified LED. None of the external lenses aquired had short enough focal lengths to collect all the light from an LED and since the required diameter was impractical this line of investigation was dropped in favour of incorporating a better lens directly on the LED.

Model 25 demonstrated a beam angle of about 5 degrees. This result is consistent with expectations because, though the lens was calculated to produce a 4° beam, the calculation was based on a .05 inch source as opposed to the actual source size of .06 inches.

The data from model 25 is shown in plot #3. Each of the lenses was plotted separately and then combinations were plotted. Lenses B and C have significantly lower luminance than lens A. A physical measurement of the lenses showed that the LED's were misaligned, with lens C being worse than lens B. The tests were intended to see if the light added correctly and this principle was demonstrated even though the lenses had different efficiencies. One attempt was made to see if the angle of dispersion could be reduced to 2 degrees using this technique. The result was model 26 which is shown in Figure 47a. A plot of the lens profile is shown in Figure 47b. This lens did not work well because of fabrication problems and LED alignment problems. It seemed to focus the light rather than collimating it.

9.3 DISCUSSION

For an optimum external collimating lens, the distance to the LED (focal length) must be such that the angle which the source subtends from any point on the lens must be less than or equal

to the desired dispersion angle. For a .2 inch LED source diameter, the focal length should be 2.86 inches. For optimum efficiency the lens should have as wide an acceptance angle as possible and certainly at least as wide as the LED beam angle (the angle between the half intensity points of the LED beam.) For an HP LED a good lens would have a diameter of at least 1.22 inches while a Stanley could obtain equal performance with a .62 inch lens.

The optimum LED lens diameter for a source with a .060 inch diameter(typical of the LED reflector itself, with the LED lens (removed) is .74 inches (to produce a 4 degree beam). A 4 degree beam may be produced with a much smaller lens as indicated by the Fairchild data sheet example in Appendix B but there is a sacrifice in light collection. Even the optimum lens must rely on the reflector bowl to concentrate all the LED light into an 82 degree beam, because its acceptance angle is fixed by the index of refraction of the lens material. See elliptical lens geometry in Aprendix A.

The data for model 25 shown in plot #3 indicate it would take 150 such lenses to equal the brightness of the existing red signal, where it would only take 120 LED's using concept 2A. The explanations for this are:

1) there were defects in the finished elipsoidal lenses;
2) the LED's were not aligned exactly with the lenses;
3) the lens calculation assumed a source diameter slightly smaller than was the actual case;(.05 instead of .06 inches)
4) indicies of refraction were not known exactly.

These lenses were only tried with red LED's although the yellow and green LED's would have twice as much beam angle improvement and over four times the improvement in luminance.

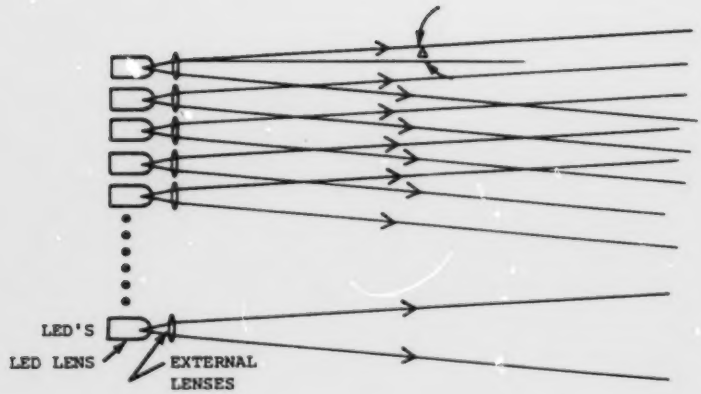


FIGURE 37a CONCEPT 3: INDIVIDUAL EXTERNAL LENSES

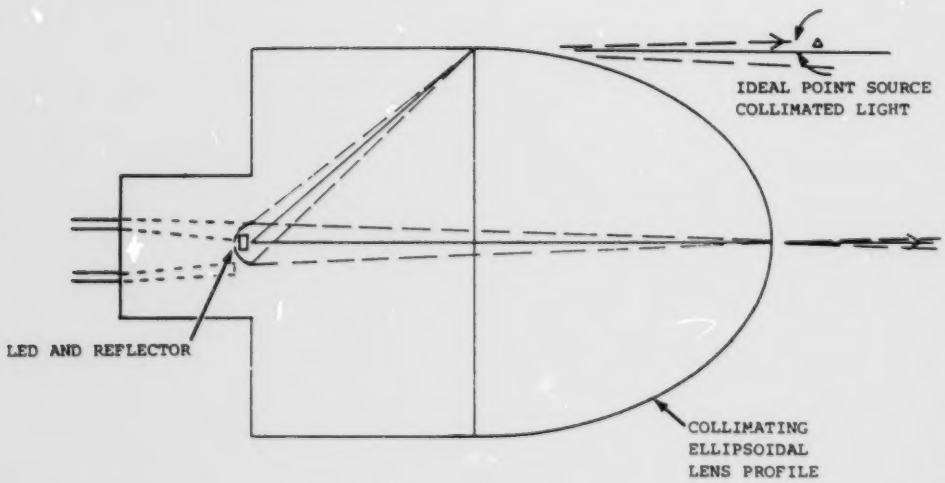
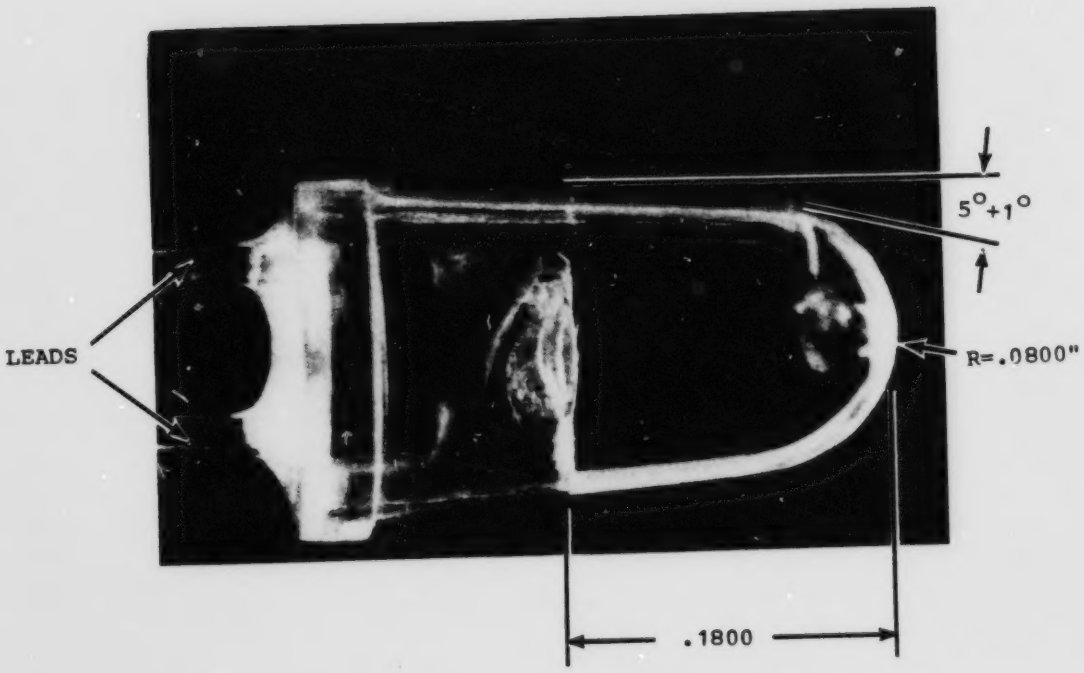


FIGURE 37b CONCEPT 3: LED LENS MODIFICATION



STANLEY LED

FIGURE 38 STANLEY H2000 LIGHT EMITTING DIODE: SIDE VIEW

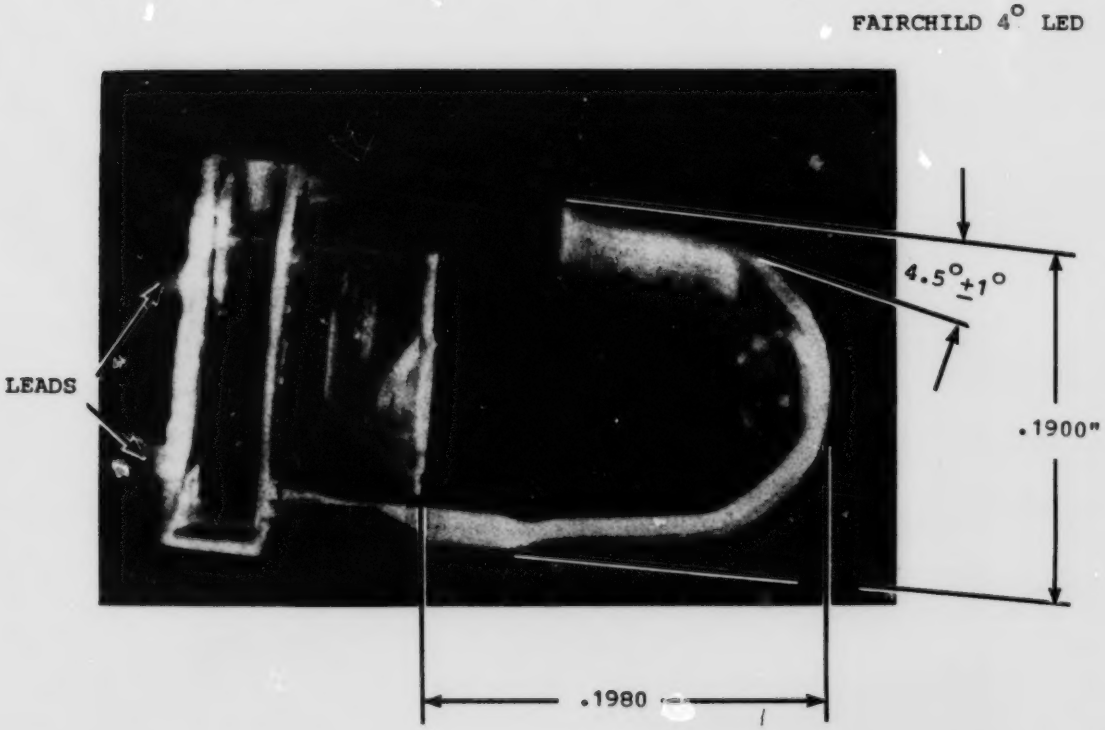


FIGURE 39 FAIRCHILD 4° LED: SIDE VIEW

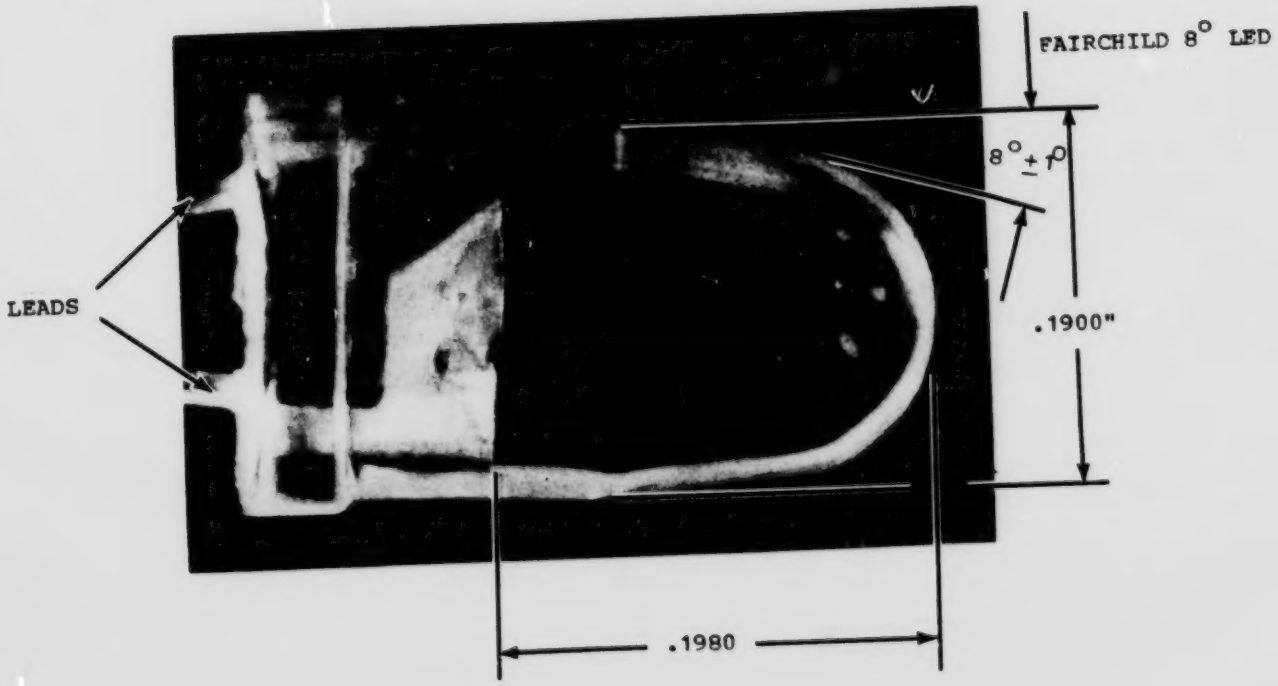


FIGURE 40 FAIRCHILD 8° LED: SIDE VIEW

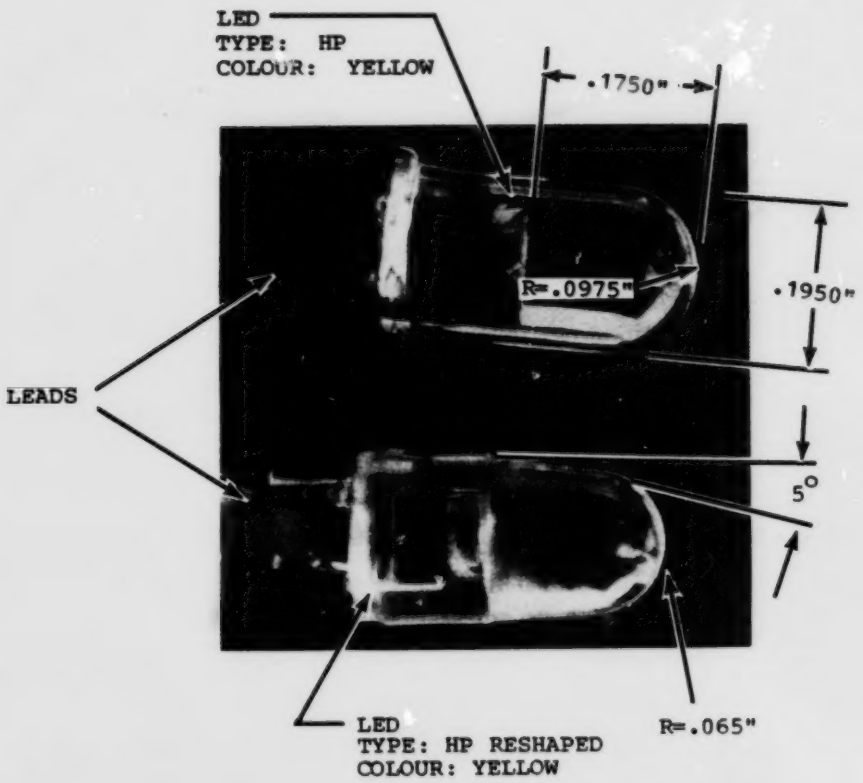
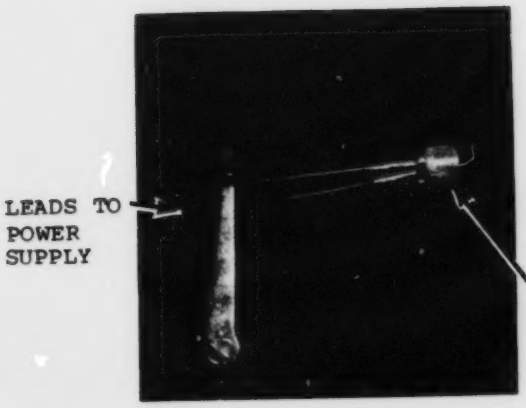
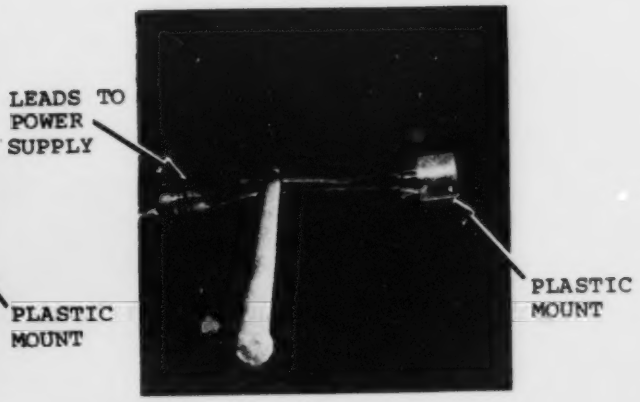


FIGURE 41 RESHAPED HELWETT - PACKARD (HP) LIGHT EMITTING DIODE (LED)



LED
TYPE: STANLEY
COLOUR: RED

FIGURE 42a CONCENPT 3 15TH MODEL



LED WITH FLAT HEAD
TYPE: HLMP 3950
COLOUR: GREEN

FIGURE 42b CONCEPT 3 18TH MODEL

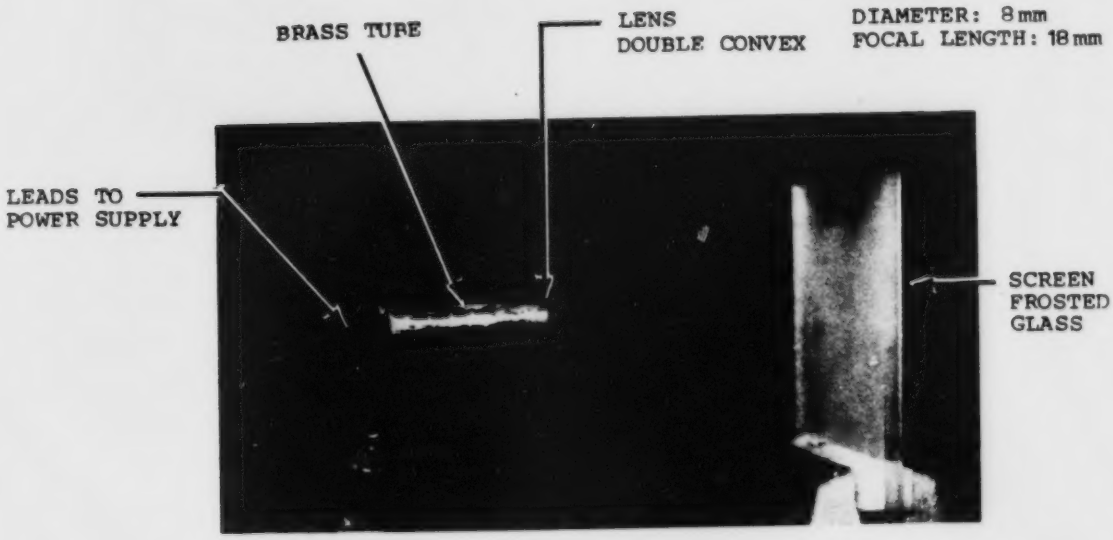


FIGURE 42c CONCEPT 3 18TH & 15TH MODEL

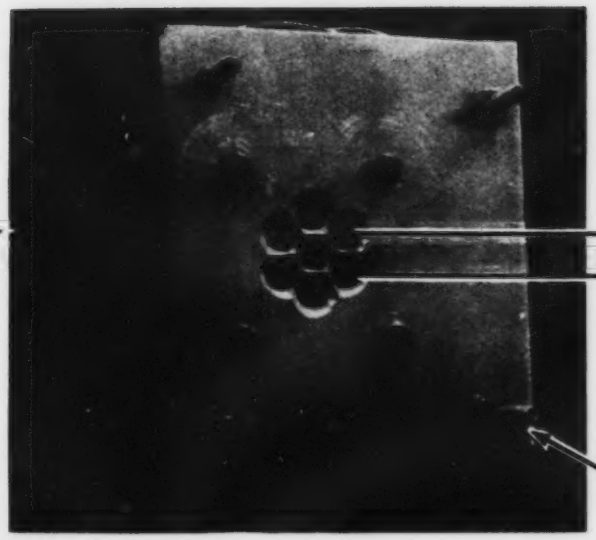


FIGURE 43a CONCEPT 3 16TH MODEL

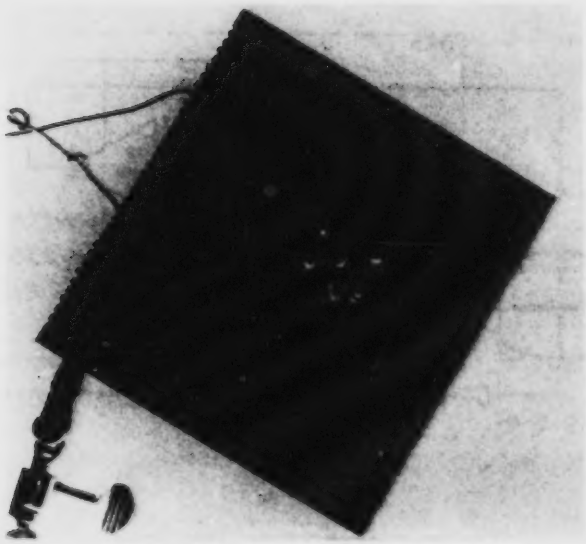


FIGURE 43b CONCEPT 3 17TH MODEL

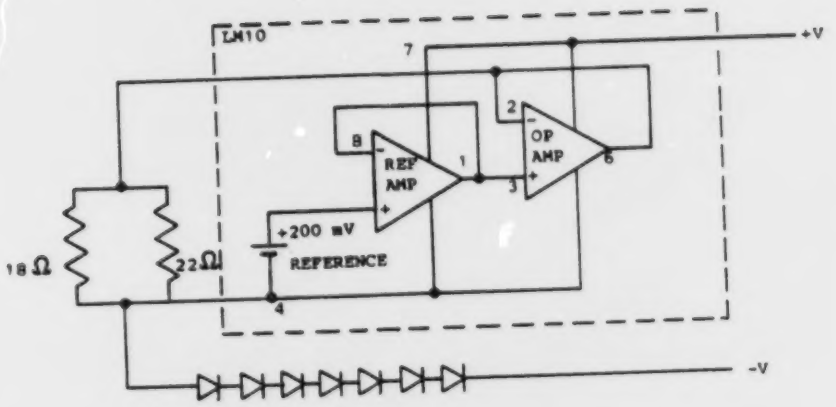


FIGURE 44a CONCEPT 3 16TH MODEL
CIRCUIT FOR DRIVING
7 HLMP 3750 RED LIGTH EMITTING DIODES

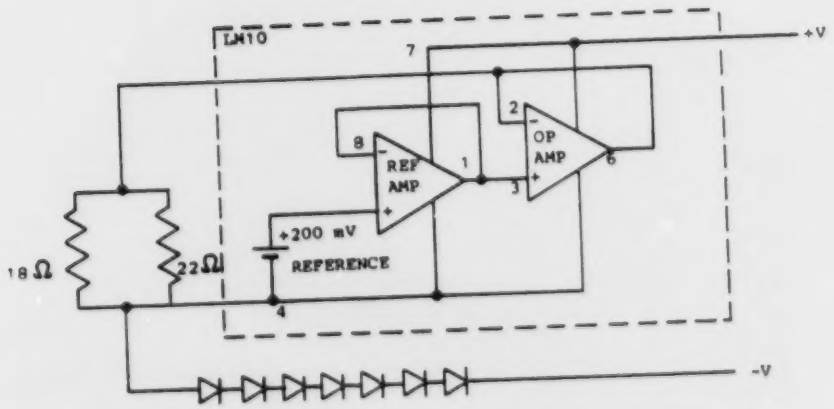


FIGURE 44b CONCEPT 3 17TH MODEL
CIRCUIT FOR DRIVING
7 STANLEY RED LIGHT EMITTING DIODES

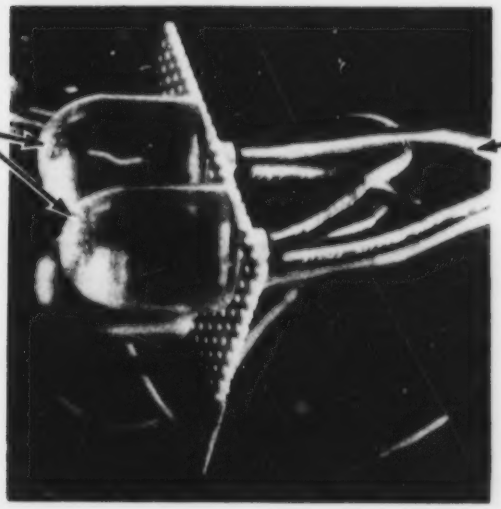


FIGURE 45a CONCEPT 3 25TH MODEL

LENS SPECIFICATIONS
DISPERSION ANGLE = 4.0°
SOURCE DIAMETER = 0.05"
ECCENTRICITY = 1:1.52
DISTANCE BETWEEN FOCAL POINTS=0.71"
LIGHT COLLECTION ANGLE = 82.3°

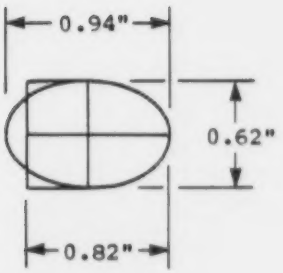
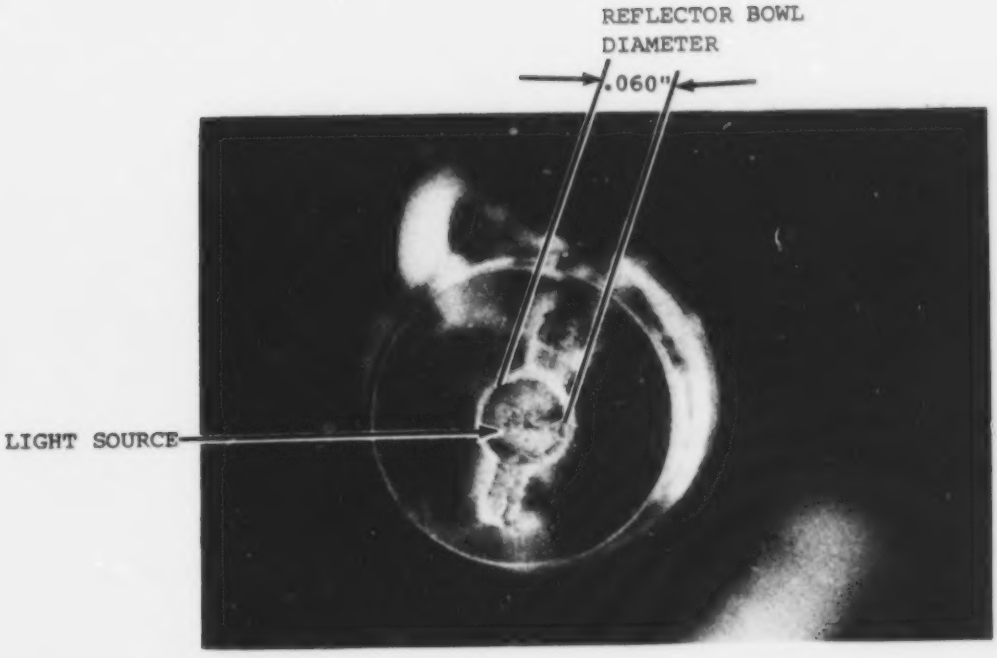
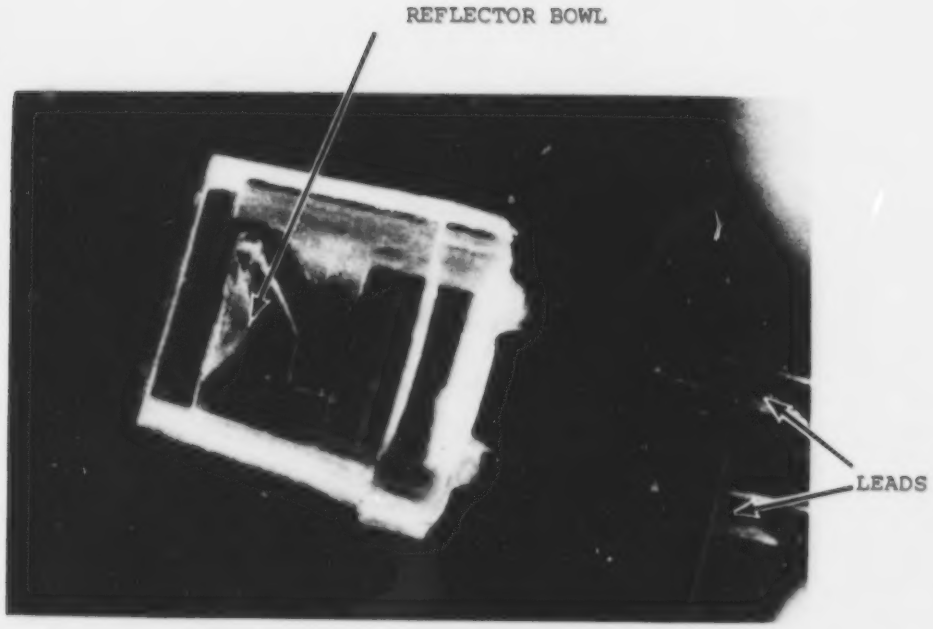


FIGURE 45b LENS: ACTUAL SIZE



LED
TYPE: STANLEY
COLOUR: RED

FIGURE 46a FLAT HEAD: TOP VIEW



LED WITH ROUND LENS REMOVED
IN PREPARATION FOR THE
MOUNTING OF A CUSTOM LENS

TYPE: STANLEY

COLOUR: RED

FIGURE 46b FLAT HEAD: SIDE VIEW

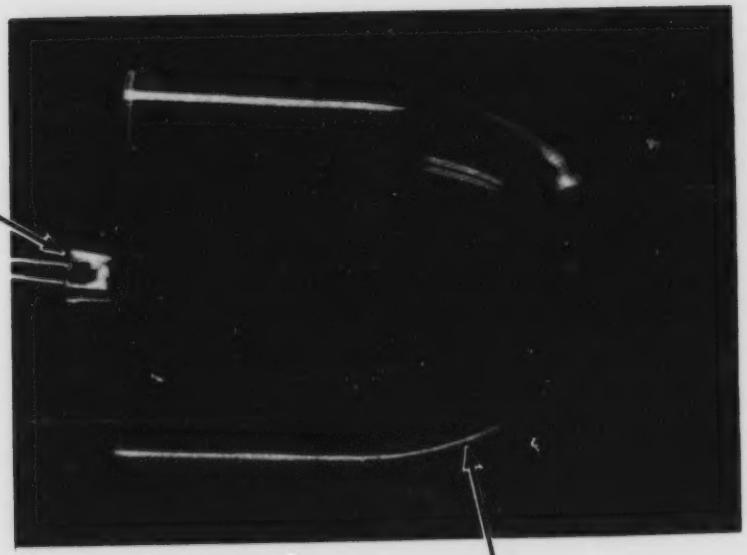


FIGURE 47a CONCEPT 3 26TH MODEL

LENS SPECIFICATIONS
DISPERSION ANGLE = 2.0^{O}
SOURCE DIAMETER = 0.06"
ECCENTRICITY = 1:1.52
DISTANCE BETWWEN FOCAL
POINTS = 1.70"
LIGHT COLLECTION ANGLE = 82.3^{O}

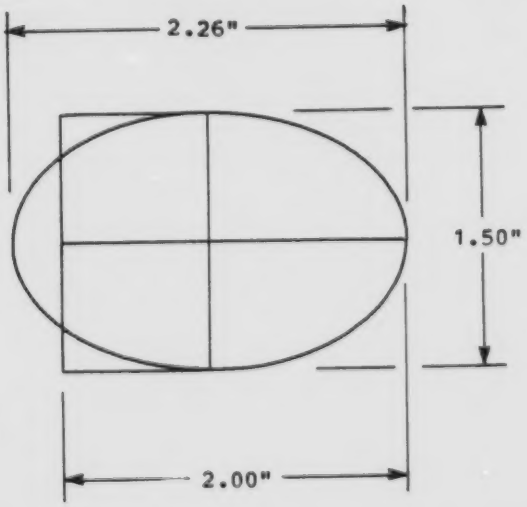


FIGURE 47b ELIPSE OF REVOLUTION FOR MODEL 26

10.0 PRELIMINARY DESIGN

The optical, electrical and mechanical design constraints on the prototype are listed in section 2.1. It was decided to base the prototype on concept 2A (model 11 or 12) as it showed the most promise optically and it was expected to be less of a problem to fabricate. In addition it could be utilized with the existing outer housing and front lens, including roundels and hot spots. Since there are two types of inner assemblies (and outer housings) in use today it was necessary to design a bracket system which would allow mounting in either a US and S unit or a GRS unit.

10.1 ELECTRICAL DESIGN

Two electrical designs were done, each having separate benefits. Both were based on compatibility with the existing signal, and both were attempts to meet railway electrical protection specifications. The first stresses reliability (sect. 10.1.1) while the second emphasizes electrical efficiency(sect. 10.1.2) Theoretically 18 watts can drive 160 to 560 LED's, depending on the required LED current and voltage. The first circuit is about 36% efficient, meaning that it is only guaranteed to be able to drive 57 LED's at a time, while the second circuit is 56% to 67% efficient, implying that it can drive at least 93 LED's. A block diagram of typical signal light electronics is shown in Figure 48 and includes sections for transient protection, power supply and colour selection.

10.1.1 Low Efficiency Circuit

The circuit shown in Figure 49 is a highly protected implementation of the block diagram in Figure 48. This design also provides consistent operation over a wide range of input voltages on both power and signal lines. The high degree of protection and signal flexibility are only achieved with a significant sacrifice in efficiency. The efficiency is closely

approximated by dividing the average voltage across any string of LED's by the lamp input voltage. In this circuit the average string voltage is about 4.4 volts and the input voltage can vary from 8v to 12v or higher, giving nominal efficiencies of 36% and best case of 55%. Note that this is only the efficiency of the circuit in supplying electrical power to the LED's. The efficiency of converting electrical energy to light and the efficiency of concentrating the light into a narrow beam are dependant on the particular LED specifications and the optical geometry respectively.

All components in the circuit are protected from breakdown to 100 volts, however as the voltage increases the power consumption also increases, eventually overheating the power transistors. There is enough thermal inertia to insure protection from transient overvoltages. Surges that would normally go beyond the breakdown limit of 100 volts are clamped to safe limits by transient absorbing devices. There is also a filter choke and capacitor to attenuate high speed voltage spikes. The design has a preliminary survival rating of:

1000 Vac or DC for 100µS
100 Vac or DC for 10mS
40 Vac or DC for 5 secs
18 Vac or DC continuous

The circuit was also designed to run from a lamp supply of 8 to 18 V AC or DC In addition the colour control signal lines are optically isolated to 3000 V, and all circuitry is isolated from the chassis. This allows common mode voltages in the kilovolt range without affecting operation. The lamp power is first rectified in case it is a.c. and then filtered.

Each of the three colours has a separate drive circuit including a power transistor, a low power op-amp and a protected power supply. When a colour is turned on the op-amp drives the power transistor to a precise voltage which lights all the diode strings of that colour. Each string consists of two diodes in series and a current setting resistor. A precise reference circuit supplies the reference for all three drivers. When a colour is supposed to be off it's reference is pulled to

zero. If the colour control signal drops out for any reason the colour 'fails' to red.

A colour sensing system was not included with this design because it would only add unnecessary complexity and a corresponding reduction in reliability to the circuit. The multiple strings of LED's provide a significant level of redundancy and they already have life expectancies in the millions of hours. (>100 years) The colour control signal may be fed back almost directly if it is essential to the lighting controller.

10.1.2 High Efficiency Circuit

Another way to implement the electronic block diagram of Figure 48 is shown in Figure 50. This circuit is not quite as well protected as the other circuit and reliability is reduced because it incorporates a DC - DC converter. It also costs more, but it has higher potential efficiency and is a simpler circuit with relaxed tolerance requirements. The input voltage may vary from 8-Volt ac or dc to 18-Volt ac or dc but transient absorbers must protect it from surges in excess of 40 V. Simple current sensing relays are shown to feedback the colour status but they may not be necessary as their reliability is lower than the rest of the circuit. The 24 volt power supply allows eight LED's to be in each string while still maintaining multiple strings for redundancy (although failure of one LED does not necessarily fail the entire string) The efficiency of this version should always be in the 50 - 60% range, depending on the efficiency of the converter. Higher efficiencies are possible if a higher converter voltage (output) is selected, but that would reduce the number of redundant LED strings. This version also provides for any control failures to produce a red signal.

10.2 ELECTRICAL DISCUSSION

Designing a drive circuit for a solid-state signal light involves trading off efficiency for reliability and protection,

as indicated by the two approaches explained above, but efficiency is also directly related to input voltage variation. If a circuit like the one in Figure 49 was designed for normal lamp voltages instead of worst case voltages its efficiency would be boosted into the 50 - 70% range; but of course at reduced voltages the luminance would drop off. (This occurs in the existing lamp but not to the same extent) Efficiency could also be boosted significantly by manually switching the circuit between a.c. and d.c. instead of designing to make it automatically handle either.

Another technique to boost the voltage (efficiency) and increase protection with an ac supply is to use a transformer instead of the DC - DC converter. This would reduce costs as well as increasing efficiency but can't be used with DC power input.

10.3 MECHANICAL DESIGN

The prototype design is based on the concept of replacing the inner lens and lamp assembly of an existing searchlight with a light, rugged, solid-state signal incorporating all three colours such that each may be electronically selected to project through the same lens system without involving physical movement of any of the components. Optically, the design utilizes concept 2A (see Figure 23) with eighty-five deflanged LEDs arranged in a regular pattern similar to that shown in Figure 32. The design integrates two printed circuit boards, a concave lens, and a terminal block into a compact removable unit capable of mounting in either of the standard signal light housings now in use. The different mounting arrangement associated with each housing is handled with an appropriate mounting bracket. One of the printed circuit boards contains the LED array and lens mount while the other contains the terminal block and control circuitry. The circuit schematic is shown in Figure 50. The LED array would inlcude 27 Stanley H2000 red LEDs, 27 Data Display 200-UGCW green LEDs and 31 National Semiconductor NSL-7310 yellow LED's but the circuit design is flexible enough to utilize better LEDs as they become

available.

10.3.1 Explanation of Drawings

A complete set of mechanical drawings of the prototype design are included in this report. Figure 51 is a drawing of the custom lens required by concept 2A to spread the LED light. The dimensions are included in the drawing and the lens calculations are shown in Appendix A. The lens is inserted into the aluminum lens holder in Figure 52 from the flange side, concave surface first, until it is stopped by the small lip at the extreme edge of the holder. Next, the plexiglass spacer/collar in figure 53 is inserted behind the lens to hold it in place. The spacer/collar and lens holder are then placed flush against the circuit board, encircling the LED array and leaving room for the LED's behind the lens as shown in Figure 55. The rear circuit board is shown in Figure 56. The lens subassembly is inserted into the box lid shown in Figure 57 from the rear so that the lens holder flange seats against the inside of the circular cutout. The five components are then bolted together in three places as shown in Figure 60. The box bottom should then be bolted to the appropriate mounting bracket. The power supply circuit board and terminal block are assembled into the bottom of the box as shown in Figure 60 and connected to the LED board before the lid is screwed down.

The mounting bracket for the G.R.S. signal light housing is shown in Figure 59 and its locking levers in Figure 58. The completed subassembly is slid into the signal housing and locked in place as shown in Figure 60. Figure 61 shows the mounting bracket for the U.S. and S. signal housing and Figure 62 shows how the system goes together. The locating pin which aligns the bracket to the housing is shown in figure 54.

10.4 THERMAL DESIGN

Standard operating and storage temperature specifications for LED's are typically $-55^{\circ}C$ to $+100^{\circ}C$ which are adequate to survive in Canadian weather. The other components specified in

the circuit designs have allowable operating temperatures between at least -40°C and +85°C. These components can be replaced by better parts if necessary. Mechanically the main problems are to insure that the aluminum lens holder doesn't contract too tightly on the inner lens in cold weather and to insure that the optical alignment is stable with temperature.

10.5 DISCUSSION

The prototype design will yield a rugged replacement assembly both smaller and lighter than the unit it replaces. The beam width will be at least as wide as the existing signal's and all three colours will be projected through the same lens system. There will be no moving parts during operation and the life expectancy of the light will be increased. The design does not inherently require any moving parts but it may be expedient to interface to existing relay logic using relays, as shown in Figure 50. The prototype will operate with no modifications to the existing power or control systems, and will be mechanically compatible with current signal housings. Fifteen of the seventeen design constraints were successfully met. The luminance constraint was partially met and chromaticity was close.

The luminance requirement depends on the application and requires further observer testing. The chromaticity problem of the green signal fails towards the safer yellow colour and is expected to be resolved with the advent of new LED's. New LED's will also reduce or eliminate the luminance weakness.

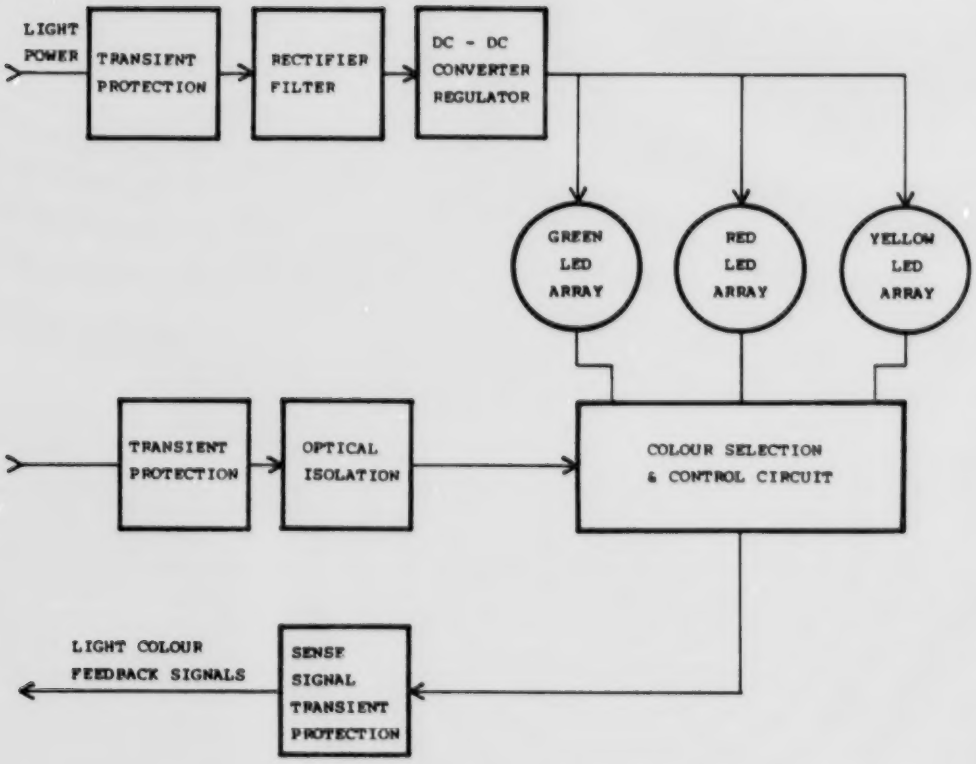
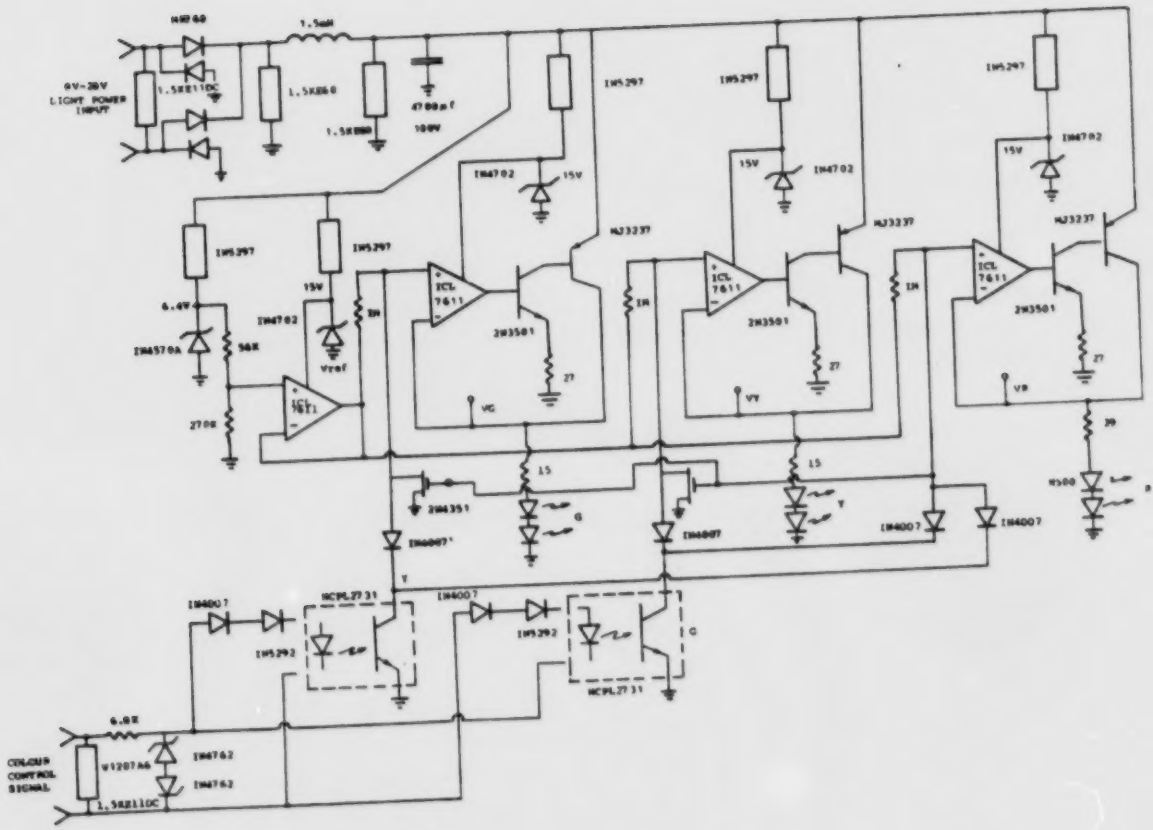


FIGURE 48 SIGNAL LIGHT ELECTRONICS BLOCK DIAGRAM



SENSE FEEDBACK NOT SHOWN

FIGURE 49 SIGNAL LIGHT ELECTRONICS LOW EFFICIENCY SCHEMATIC

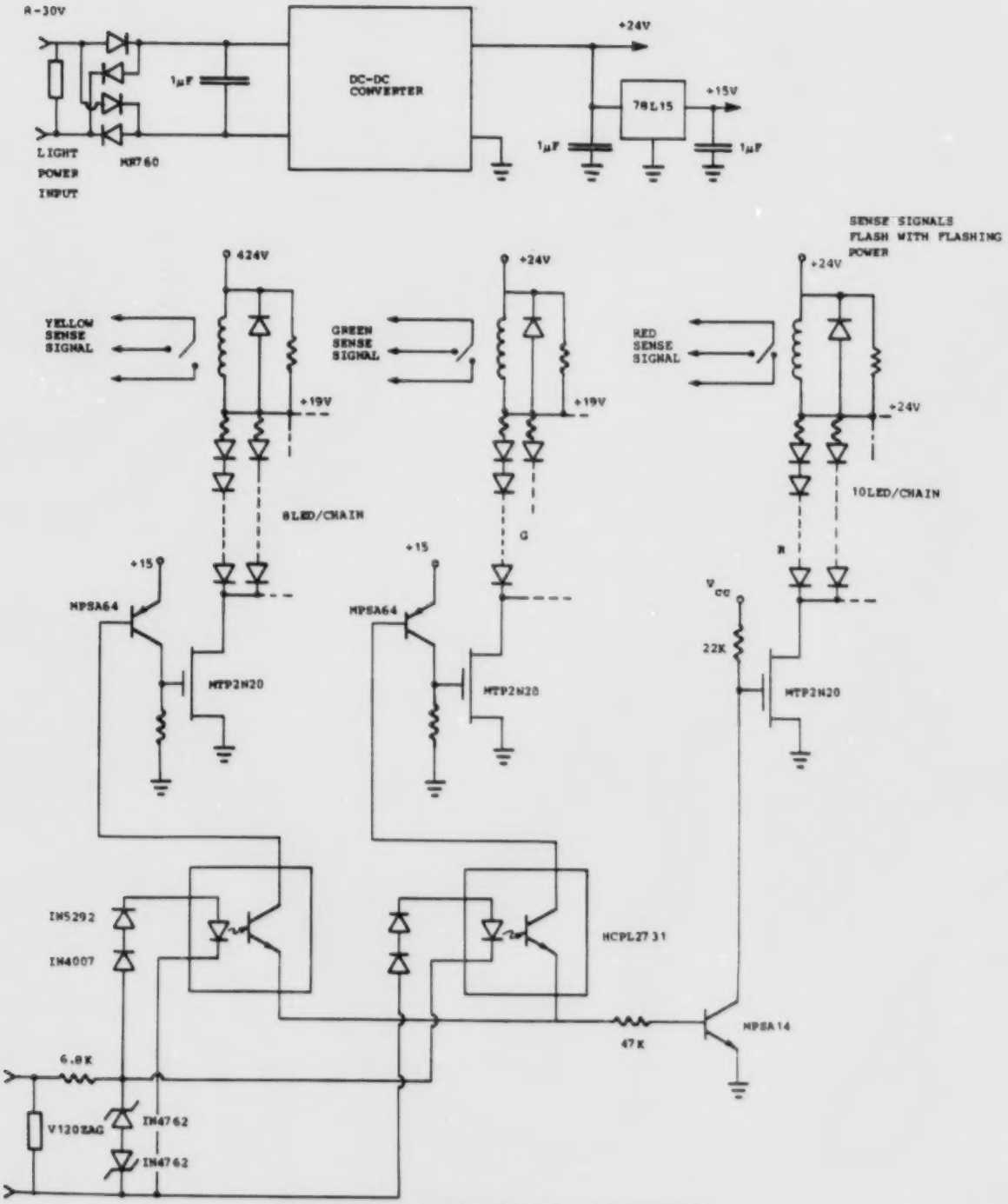


FIGURE 50 SIGNAL LIGHT ELECTRONICS
HIGH EFFICIENCY SCHEMATIC

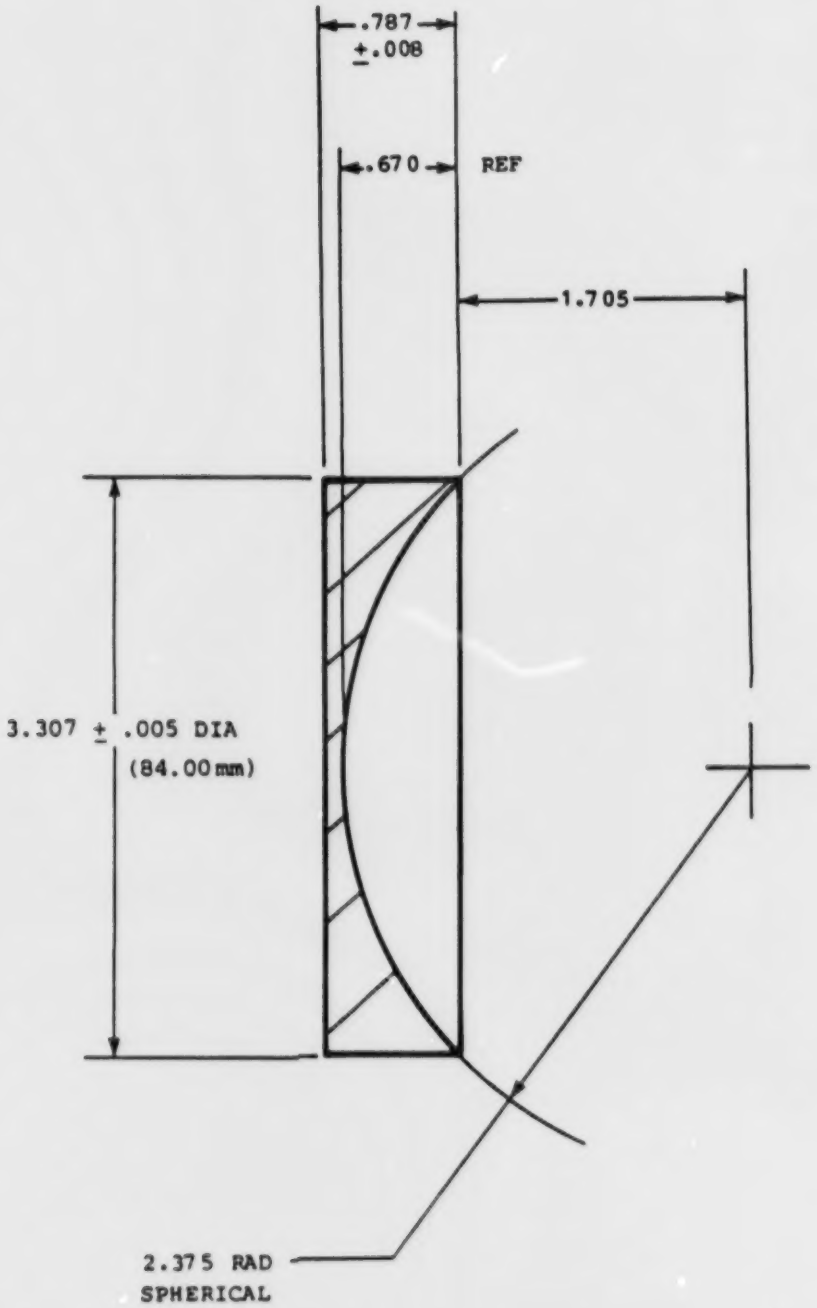


FIGURE 51 PLANO-CONCAVE LENS

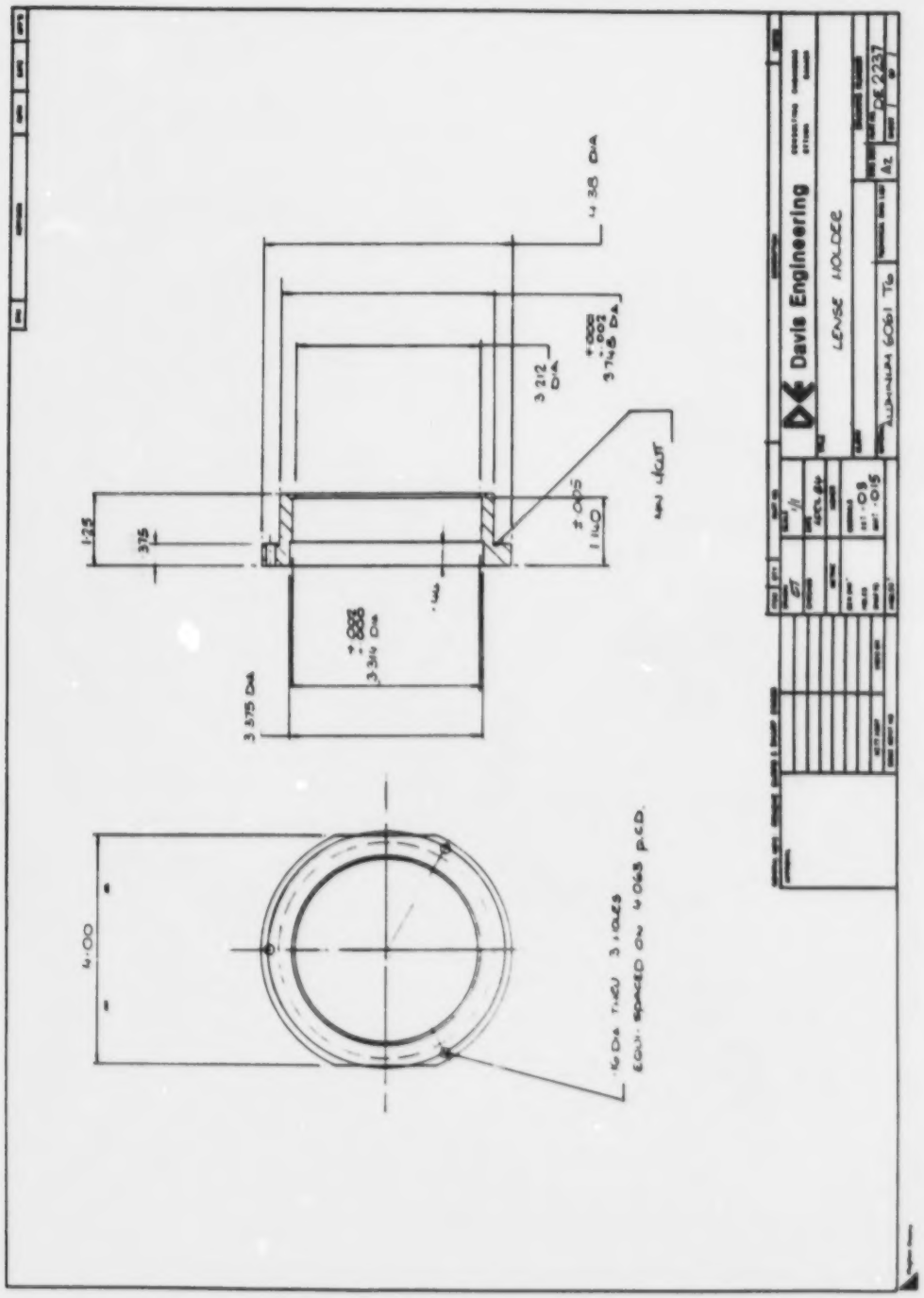


FIGURE 52 LENS HOLDER

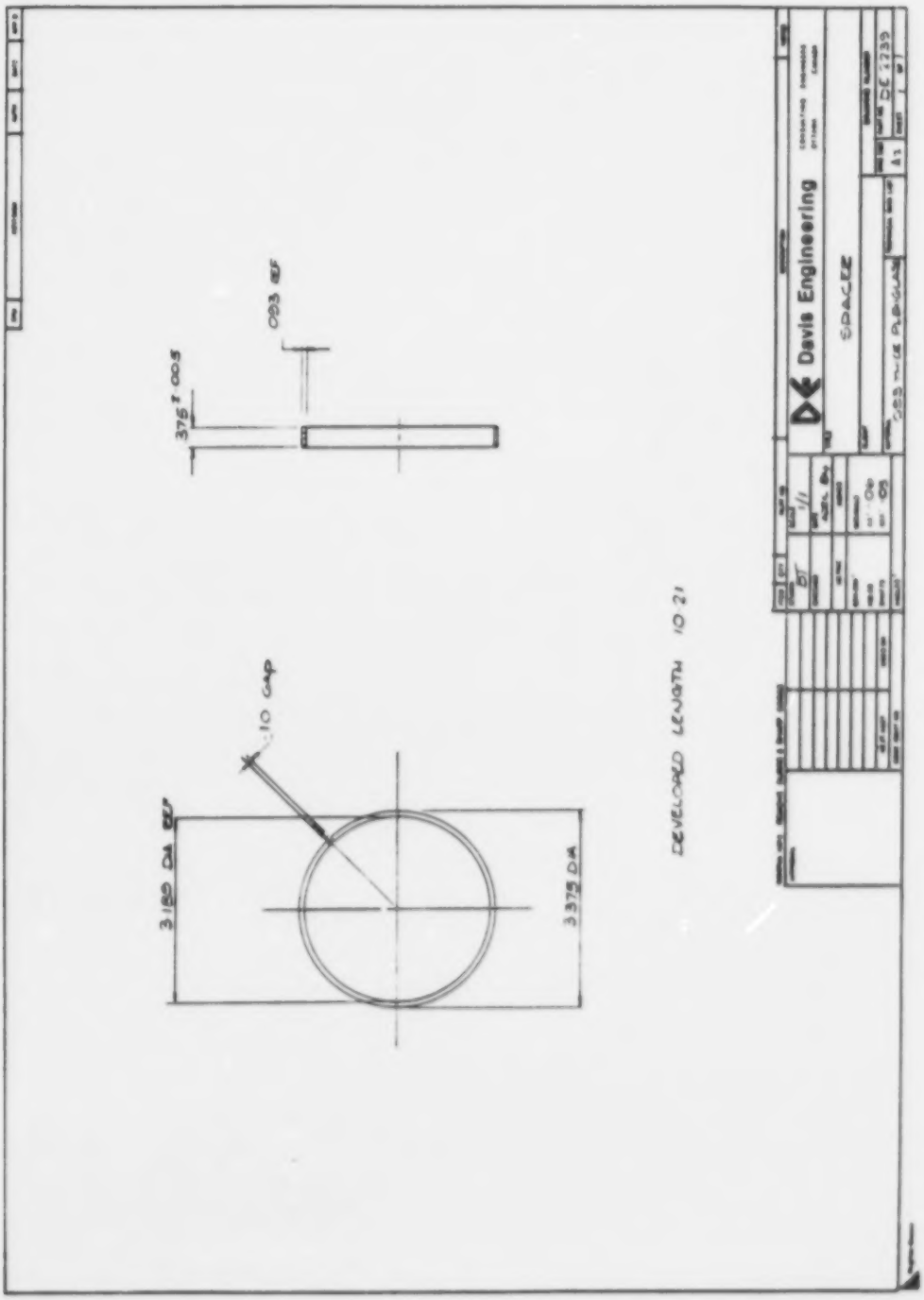


FIGURE 53 SPACER

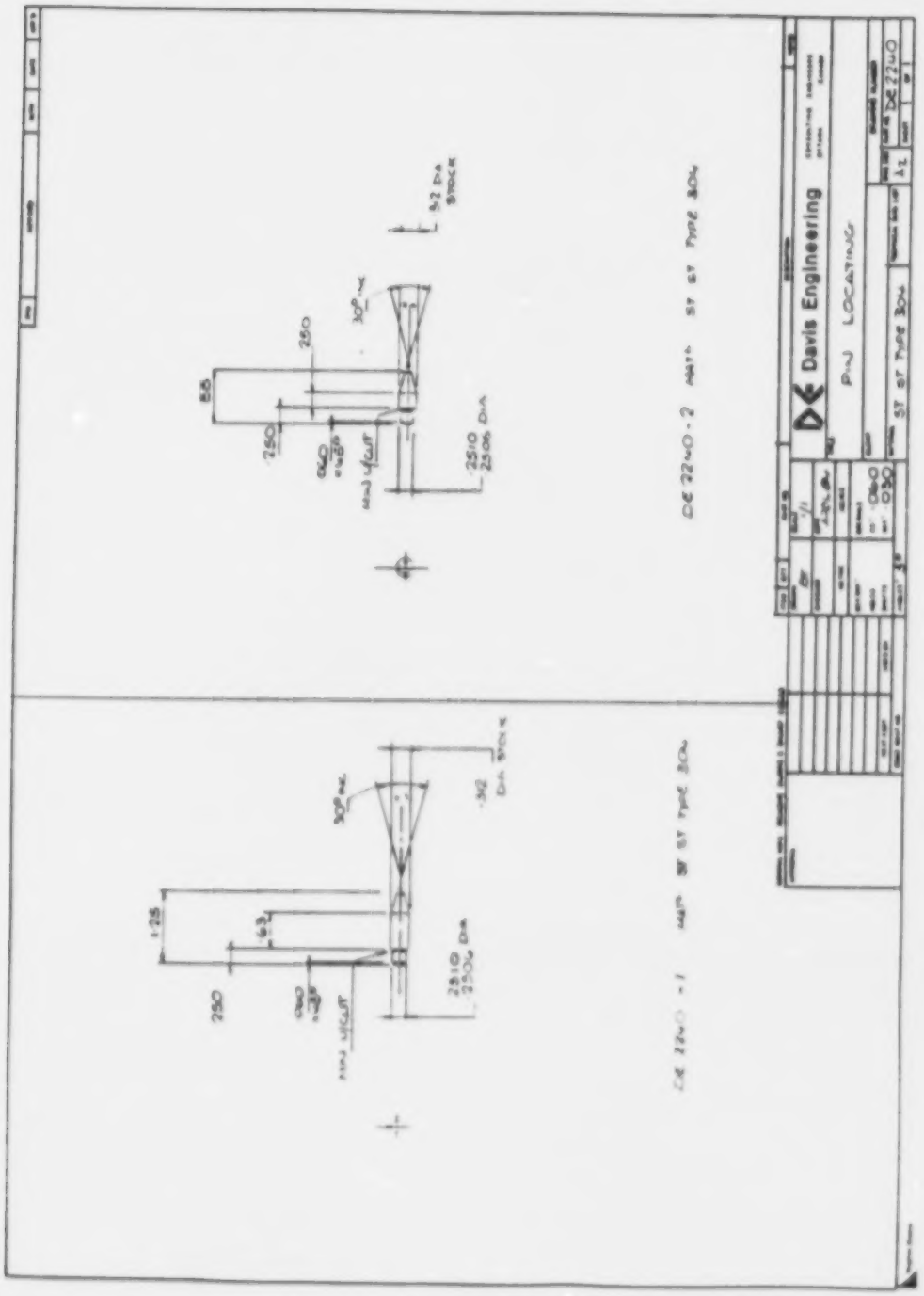


FIGURE 54 LOCATING PIN

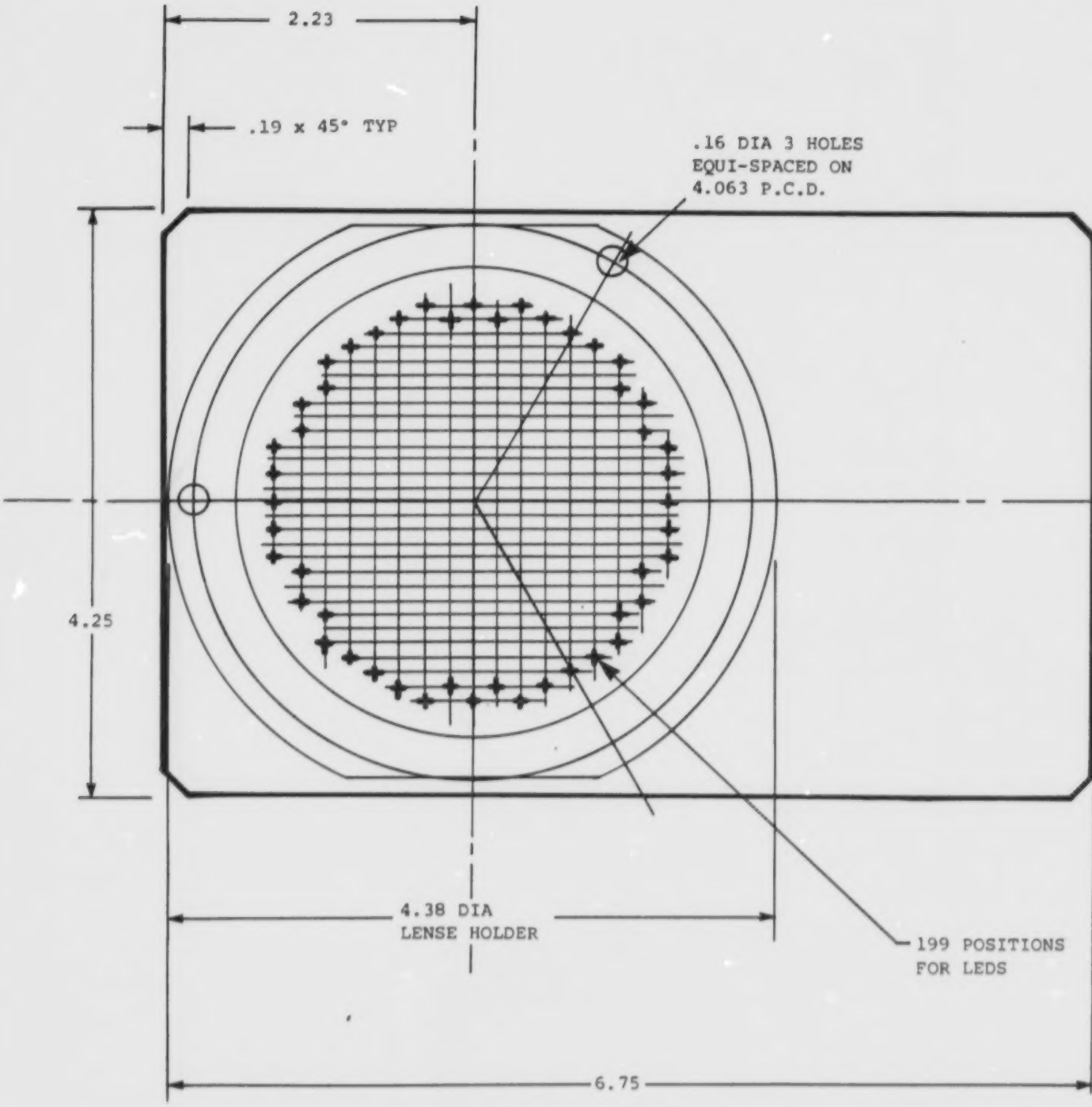


FIGURE 55 CIRCUIT BOARD: FRONT

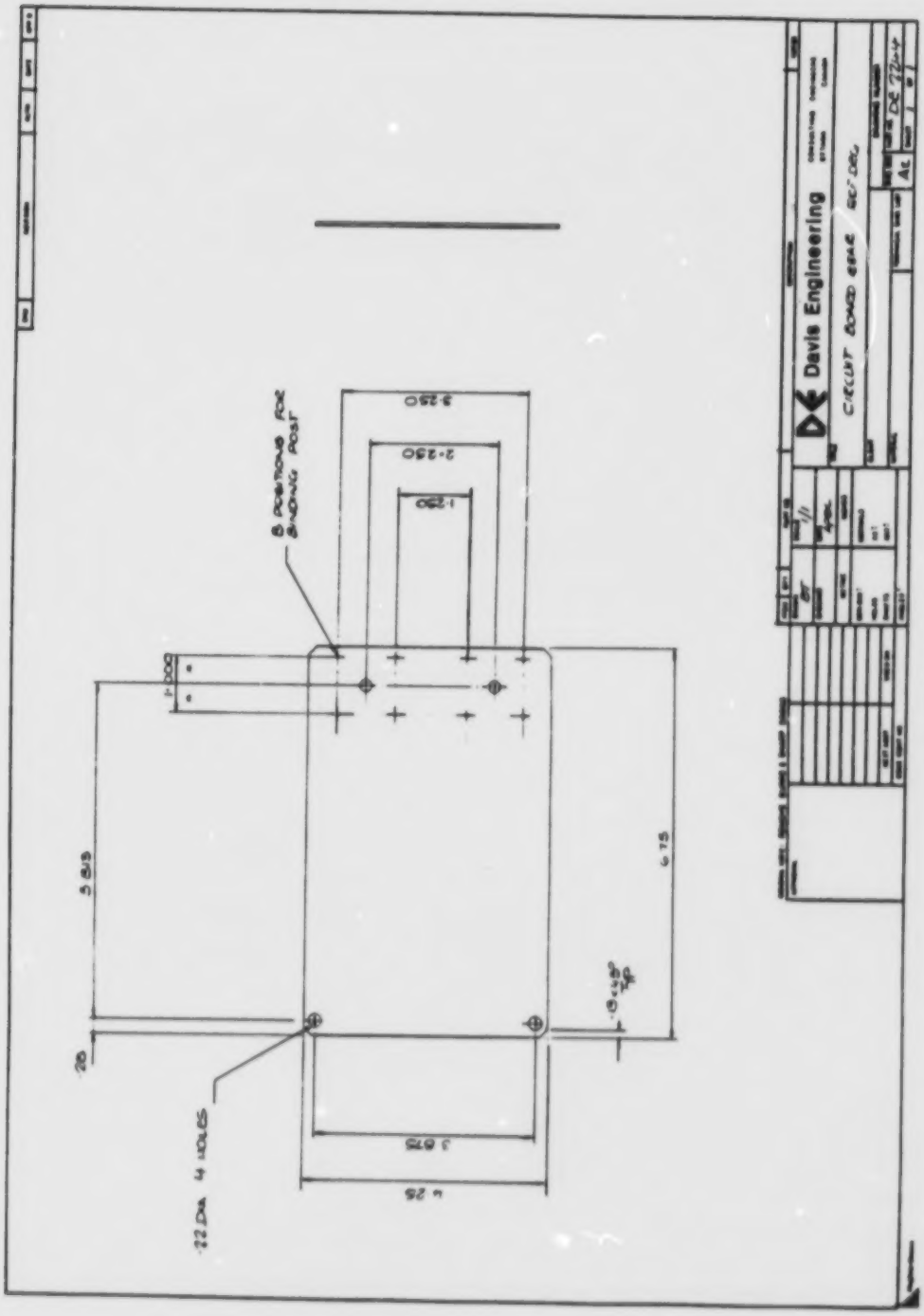


FIGURE 56 CIRCUIT BOARD: REAR

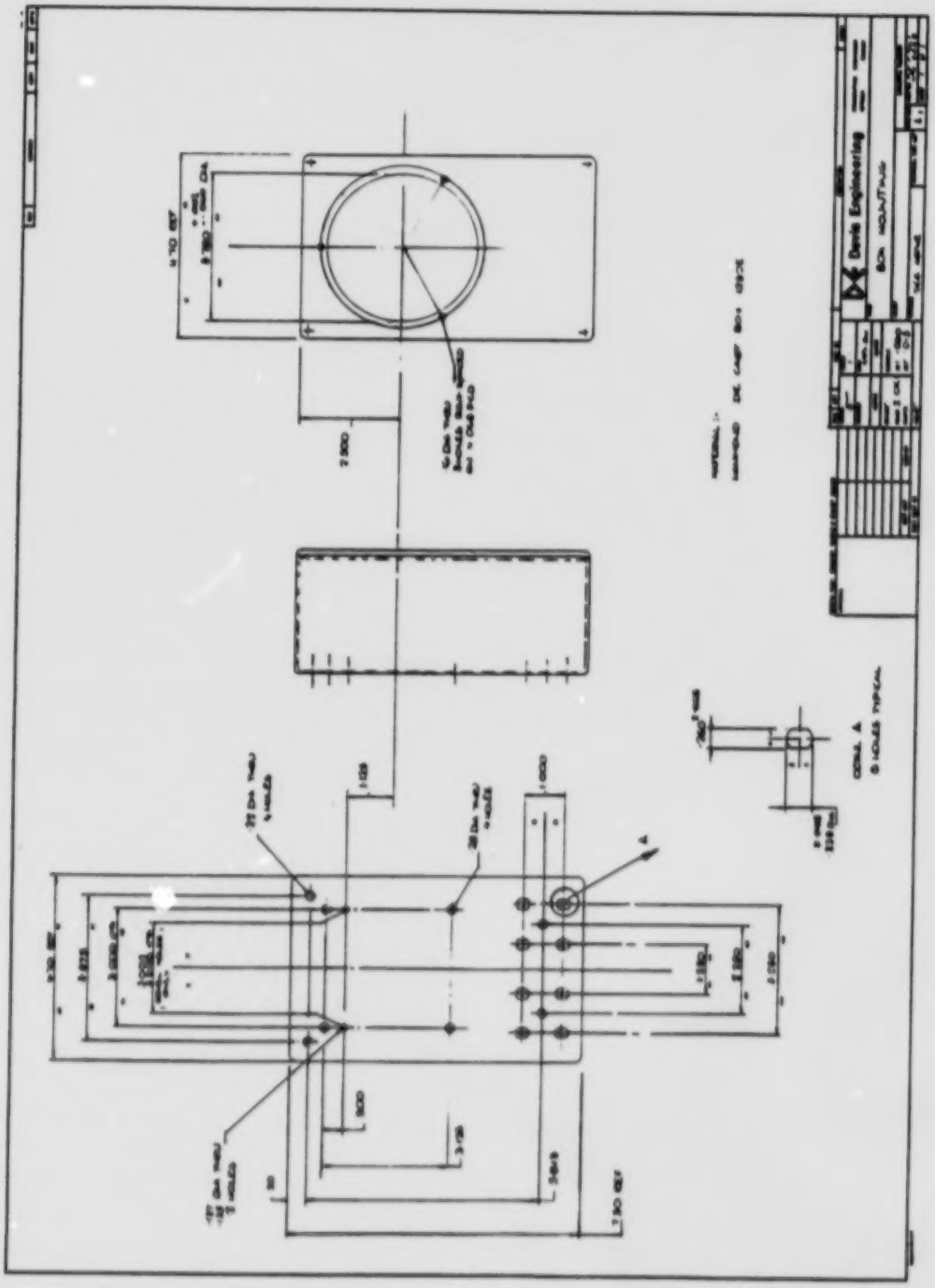


FIGURE 57 MOUNTING BOX

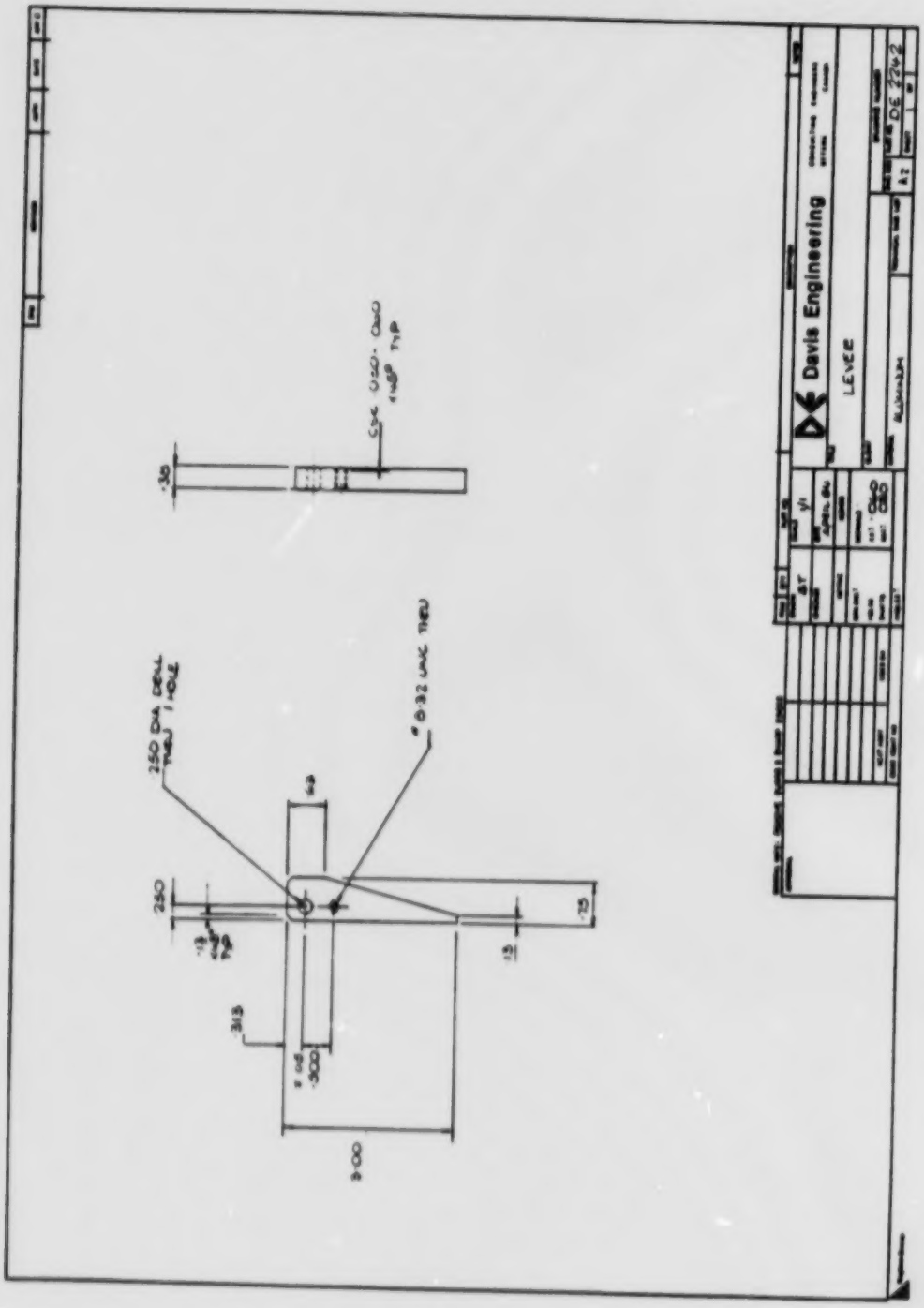


FIGURE 58 LEVER

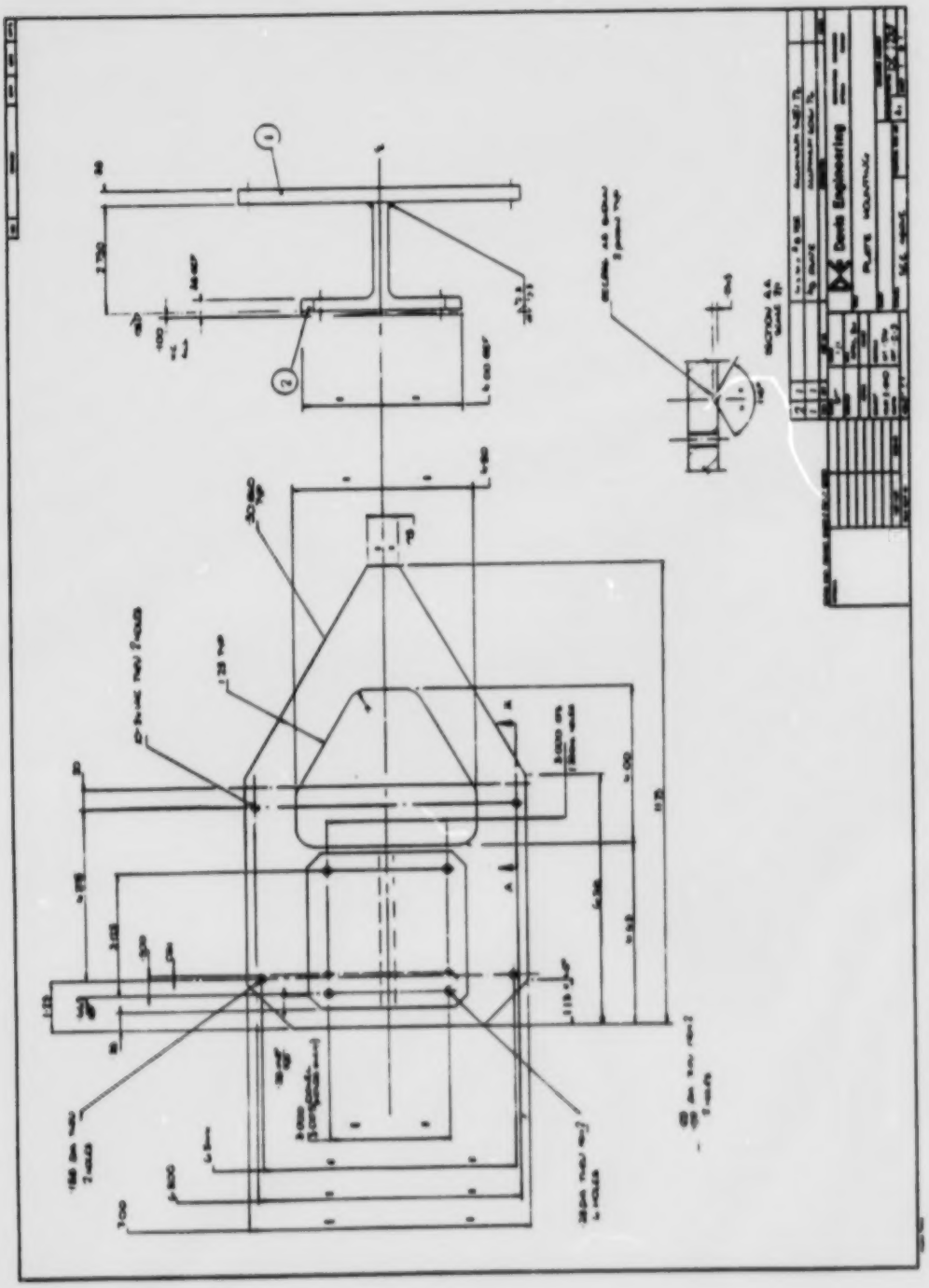


FIGURE 59 MOUNTING PLATE

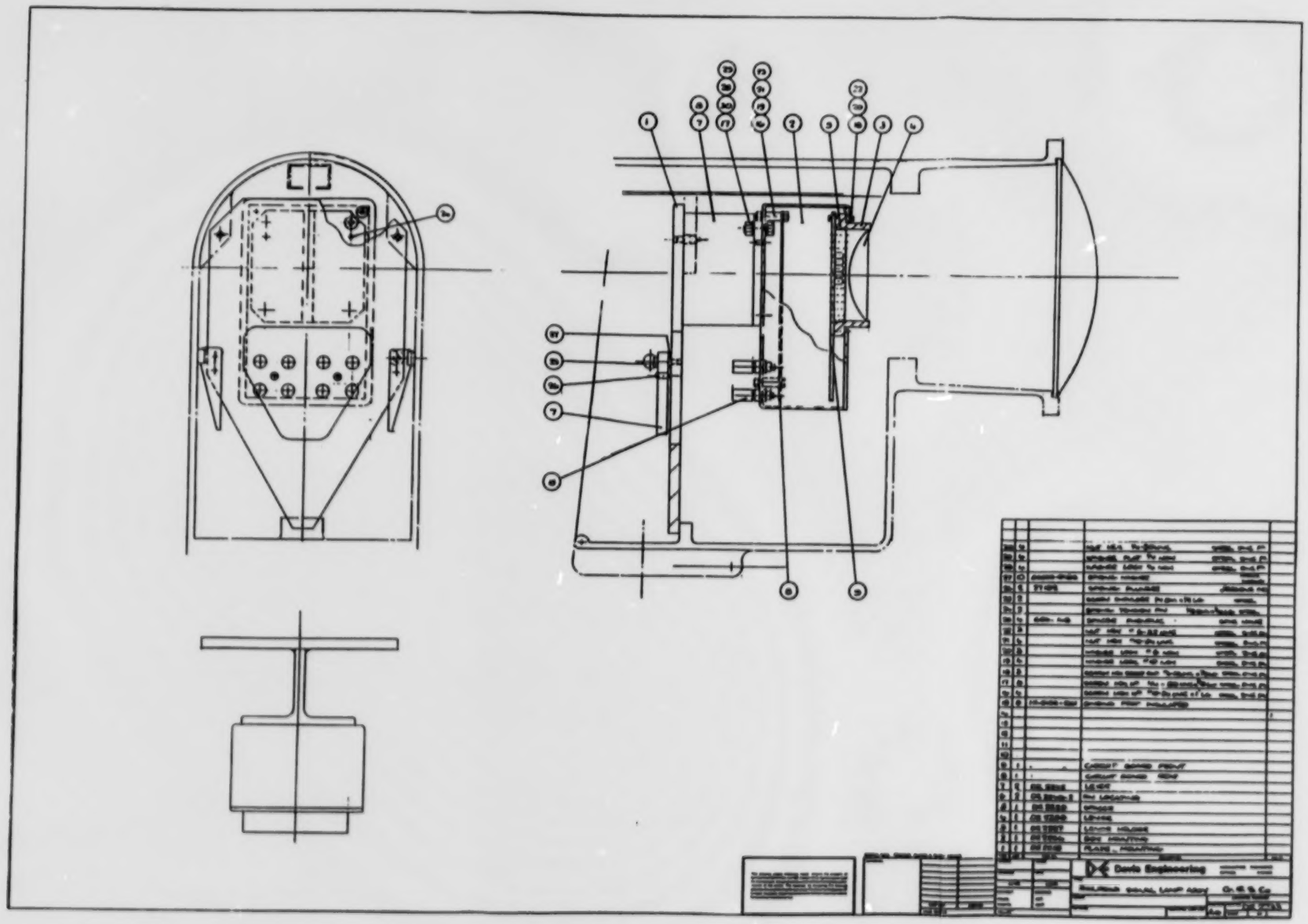


FIGURE 60 RAILROAD SIGNAL LAMP ASSEMBLY G.R.S. CO.

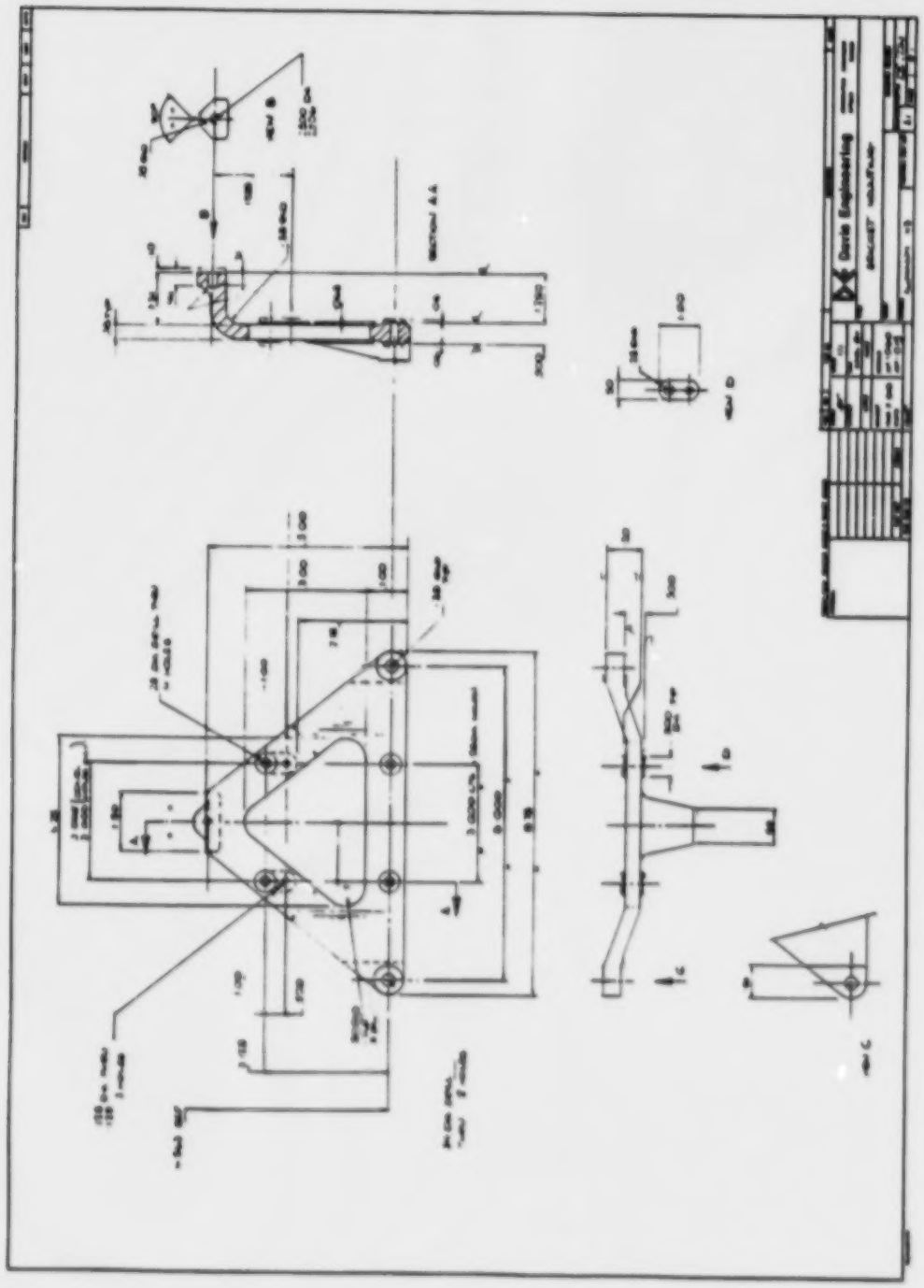


FIGURE 61 MOUNTING BRACKET

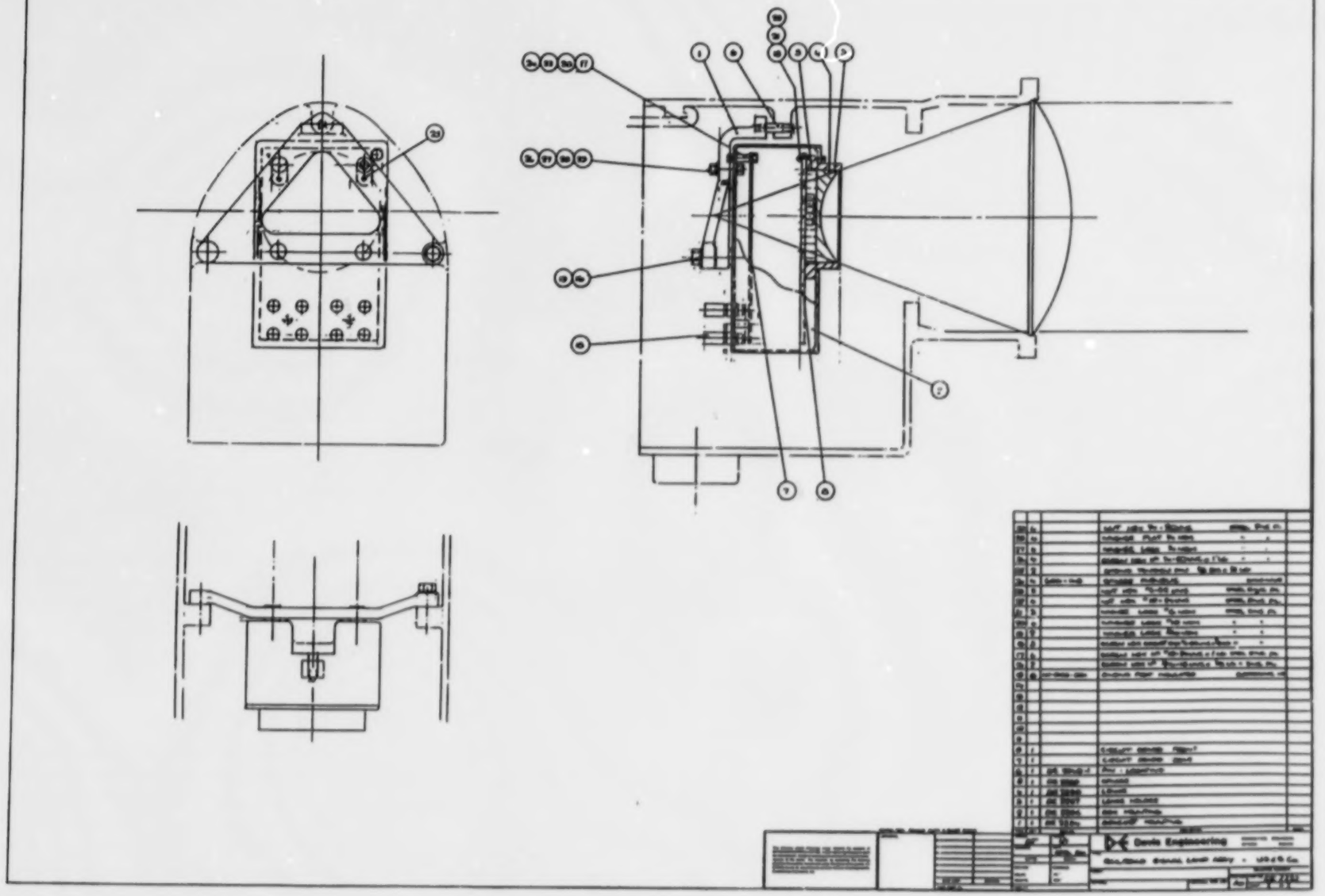


FIGURE 62 RAILROAD SIGNAL LAMP ASSEMBLY U.S. & S. CO.

11.0 CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the information compiled while investigating the basic ground rules involved in designing multi-colour, solid-state signal lights for railroad usage.

The project objective to research and model a full sized, working, solid-state railway signal light was fulfilled and a complete preliminary design was executed to indicate how such a device would integrate with current systems.

The ten electrical and mechanical design goals listed in Section 2.1 were met by the preliminary design described in Section 10. These included electrical and mechanical compatibility with existing equipment, reduced power consumption, ruggedness and transient protection (see Section 10.5 for further details).

In addition, six of the eight optical design goals (see Section 2.1) were fully met, including beam width, extended lamp life, inherent immunity from phantoms, and projecting the three colours through the same lens system without moving parts.

The only two areas of concern are luminance (brightness) and chromaticity (colour) of yellow and green LEDs. Existing red LEDs are fully adequate in both luminance and chromaticity Current yellow LEDs are very close to the AAR chromaticity specification and the technology exists to fabricate LEDs with correct yellow chromaticity so this is not seen as a major problem.

Throughout this report, the emphasis has been on direct comparison of models with existing signal lights whose distance visibility criterion extends to 5000 feet, however, the contract design guidelines specified a minimum range of 1000 feet which reduces the luminance requirement by a factor of 25. Current yellow and green LEDs are close to satisfying this relaxed requirement as indicated by comparing LED model results to normal searchlight results divided by 25, however, the best

way to determine their actual suitability is through controlled field testing. It is anticipated that packaging yellow and green LEDs with the same epoxy lens as that used on red LEDs will improve beam angle and luminance enough to meet the reduced requirements.

It should be noted that implementation of the preliminary design described in Section 10 will result in significantly improved performance over any previous model, even with existing LEDs, because the number of LEDs has been increased to 199 (160%), while still using less than 18 watts. It is also flexible enough to accomodate any improved LEDs which become available, so that even if one LED type is replaced later, all optical, mechanical and electrical field test results will remain valid and useful.

The last area of concern is the chromaticity of current green LEDs. Specifically, they do not contain enough blue spectral components, although it is significant that the only colour the green LEDs could possibly be mistaken for is yellow which is the safer (more cautionary) colour. The short term solution to this problem is to utilize a mixture of blue and green LEDs although early prototypes would still provide useful test data without blue LEDs. A cleaner but less controllable solution is to make LED manufacturers aware of the AAR chromaticity specifications and wait for compliant LEDs to be developed. For optimum results, the two approaches should be pursued in parallel.

In summation, the three-colour solid-state searchlight concept shows great promise, especially for the range up to 1,000 feet. The problems with luminance and chromaticity are short term and reflect the use of the currently available LEDs. Because LEDs with higher luminances and wider colour ranges are being brought to market monthly, it is our recommendation that the development be continued by implementing several prototypes for field testing, similar to the original plan envisioned for Phase II and that the latest available devices be used in these prototypes.

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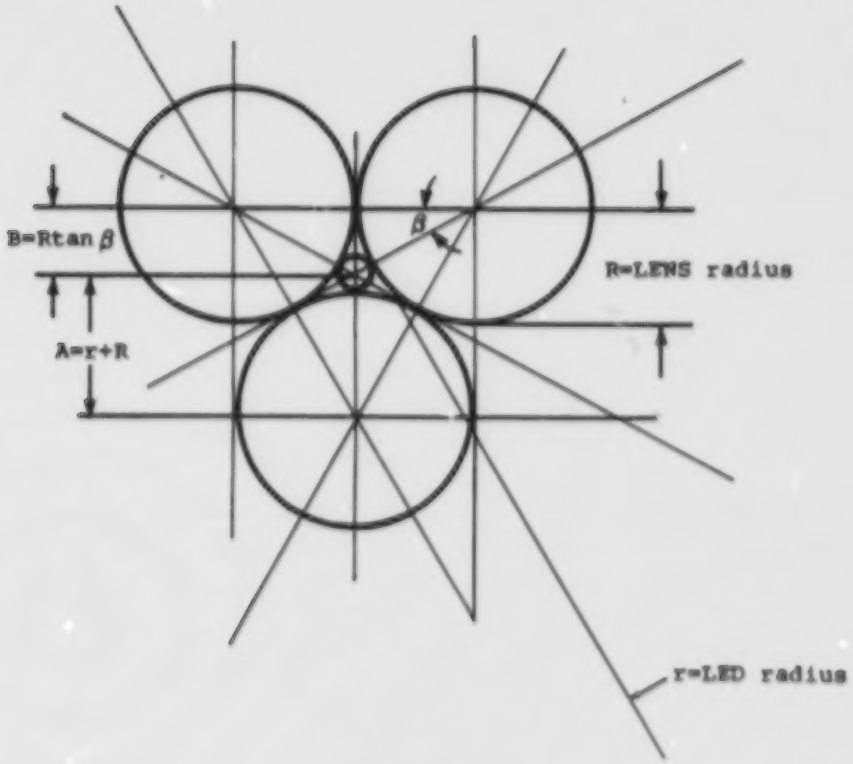
APPENDIX A

Research Data

- Interstitial LED calculation
- Concept 2, optimum radius derivation
- Concept 2a, Plano-Concave lens calc.
- Concept 2a, Bi-Concave lens calc.
- Concept 3, Ellipsoidal lens calc.
- Concept 3, lens plots (4)
- Concept 3, lens array plots (4)
- Concept 2a diode array plot

Luminance vs Angle Plots - by colour (3)
- single LEDs
- concept 1 vs concept 2



$$\tan\beta = \frac{R}{2R}$$

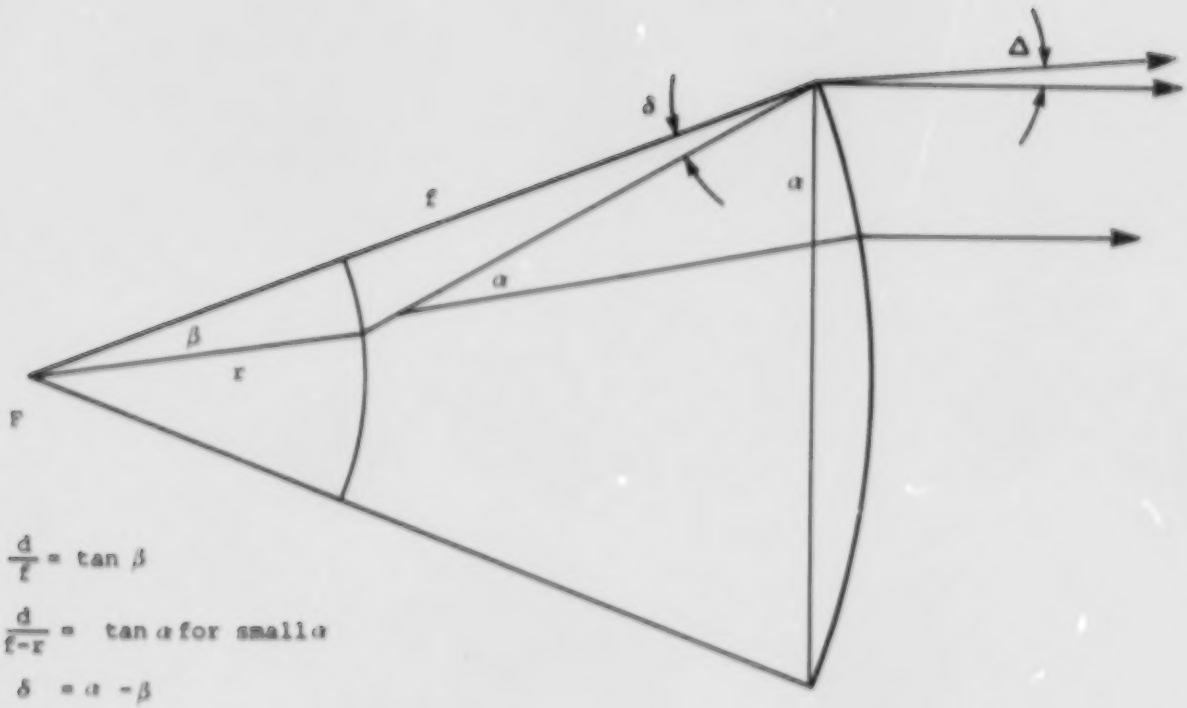
$$\cos\beta = \frac{R}{r+R}$$

$$\frac{1}{\cos B} = \frac{r}{R} + 1$$

$$R = \frac{r}{1/\cos B - 1}$$

r	R
.200"	1.29282
.205	1.325
.210	1.3575
.215	1.3898
.220	1.422
.225	1.4544
.270	1.4867

CONCEPT 3 CALCULATION OF LENS RADIUS REQUIREMENTS FOR INTERSTITIAL LED



$$\frac{d}{f} = \tan \beta$$

$$\frac{d}{f-r} = \tan \alpha \text{ for small } \alpha$$

$$\delta = \alpha - \beta$$

$$\frac{f}{f-r} \tan \beta = \tan \alpha$$

$$\beta = \tan^{-1} \left(\frac{f-r}{f} \tan \alpha \right)$$

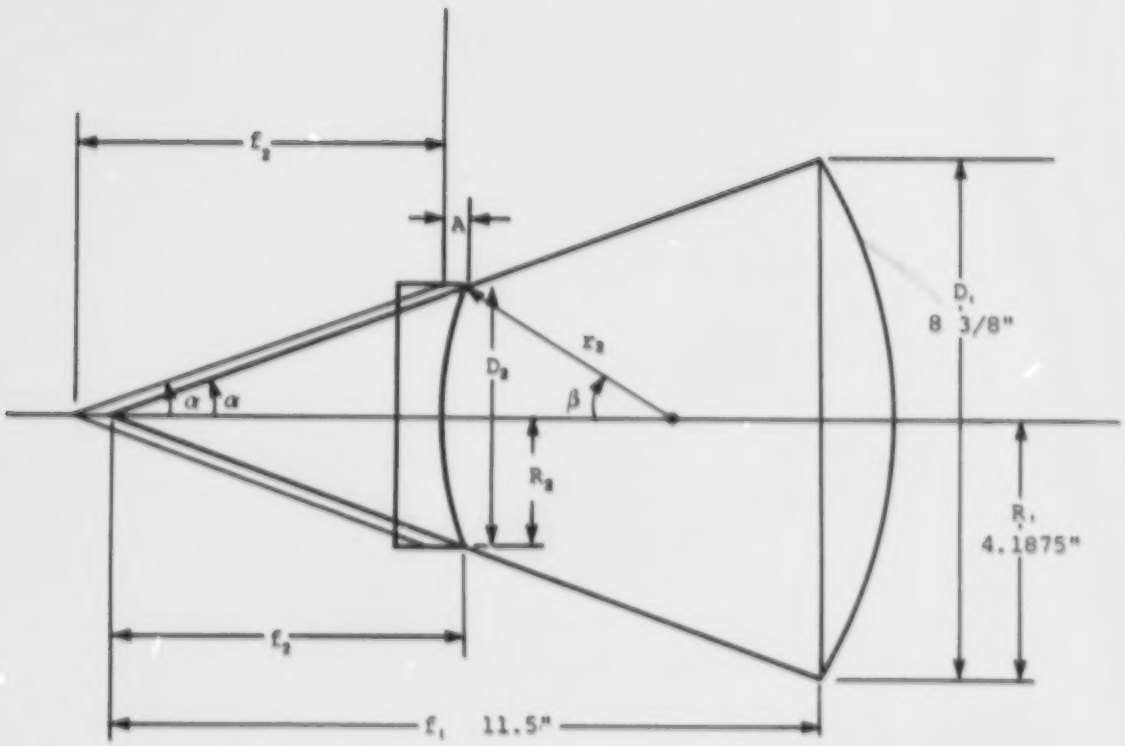
$$\delta = \alpha - \tan^{-1} \left(\frac{f-r}{f} \tan \alpha \right)$$

$$\frac{f-r}{f} \tan \alpha = \tan (\alpha - \delta)$$

$$f-r = \frac{f}{\tan \alpha} \tan (\alpha - \delta)$$

$$r = f - f \left(\frac{\tan (\alpha - \delta)}{\tan \alpha} \right)$$

CONCEPT 2 OPTIMUM r CALCULATION



$\alpha = \tan^{-1} \quad R_1/f_1$

$\beta = \sin^{-1} \quad R_2/r_2$

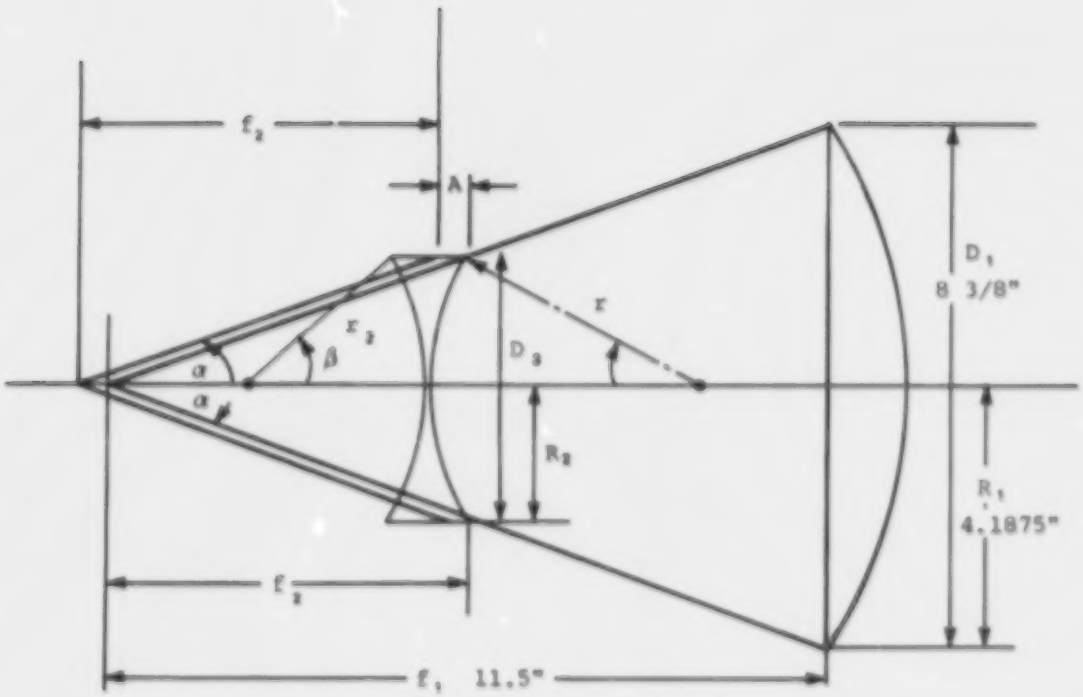
$f_2 = R_2/\tan\alpha = \dfrac{R_2 f_1}{R_1}$

$A = r_2 - r_2 \cos f$

$1/f_2 = (n - 1)/r_2$

$r_2 = f_2 (n - 1)$

CONCEPT 2A PLANO-CONCAVE LENS CALCULATIONS



$\alpha = \tan^{-1} \quad R_1/f_1$

$\frac{1}{f_2} = (n - 1)\ (\frac{2}{r_2})$

$f_2 = R\ /\tan\alpha = \frac{R_2 f_1}{R_1}$

$r_2 = 2f_2\ (n - 1)$

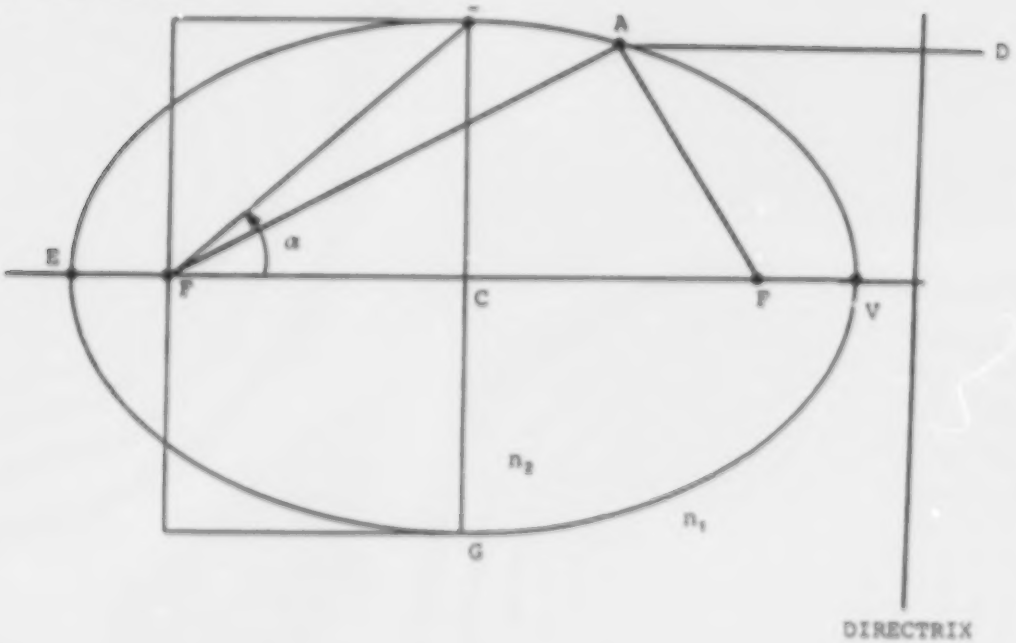
CONCEPT 2A LENS CALCULATIONS

F_1, F_2 - FOCAL POINT OF THE ELLIPSE

E, V_1 - VERTEX OF THE ELLIPSE

$\overline{EV}$ - MAJOR AXIS

$\overline{BG}$ - MINOR AXIS



$\overline{F_1F_2} + \overline{2F_2V} = \overline{F_1B} + \overline{F_2B}$

$= \overline{EV}$

$= 2\overline{F_2B}$

$\sin\alpha = \overline{BC}/\overline{FB} = 2\overline{BC}/\overline{EV} = n_1/n_2 = e$

$n_1 = 1.00$

$n_2 = 1.52$

LED BOWL DIAM = .05"

$\overline{F_1B} = \frac{.05 \sin\alpha}{\tan 2^\circ}$

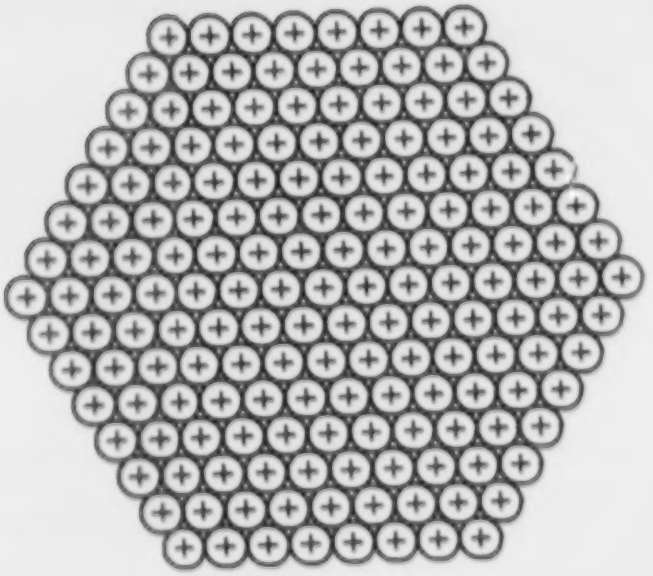
$\alpha = 41.13951041^\circ$

$\overline{F_1V} = 1.651397994$

$\overline{EV} = 1.883964032$

$\overline{EG} = 1.239450021$

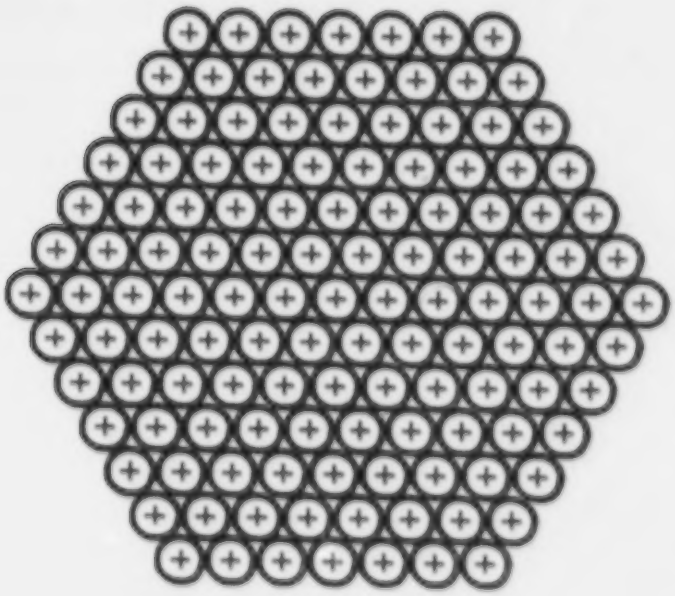
$\overline{F_1F_2} = 1.418831956$



ARAYPL.FTN
LENS DIAMETER = 0.24430
NUMBER OF DIODES = 169.
α = 12°

CNLENS.FTN
UNITS = INCHES & DEGREES

DISPERSION ANGLE	=	12.00000
SOURCE DIAMETER	=	0.06000
N2	=	1.52000
SOURCE TO VERTEX	=	0.32557
F1F2	=	0.27972
MAJOR AXIS	=	0.37142
MINOR AXIS	=	0.24435
LIGHT COLLECTION ANGLE	=	82.27890



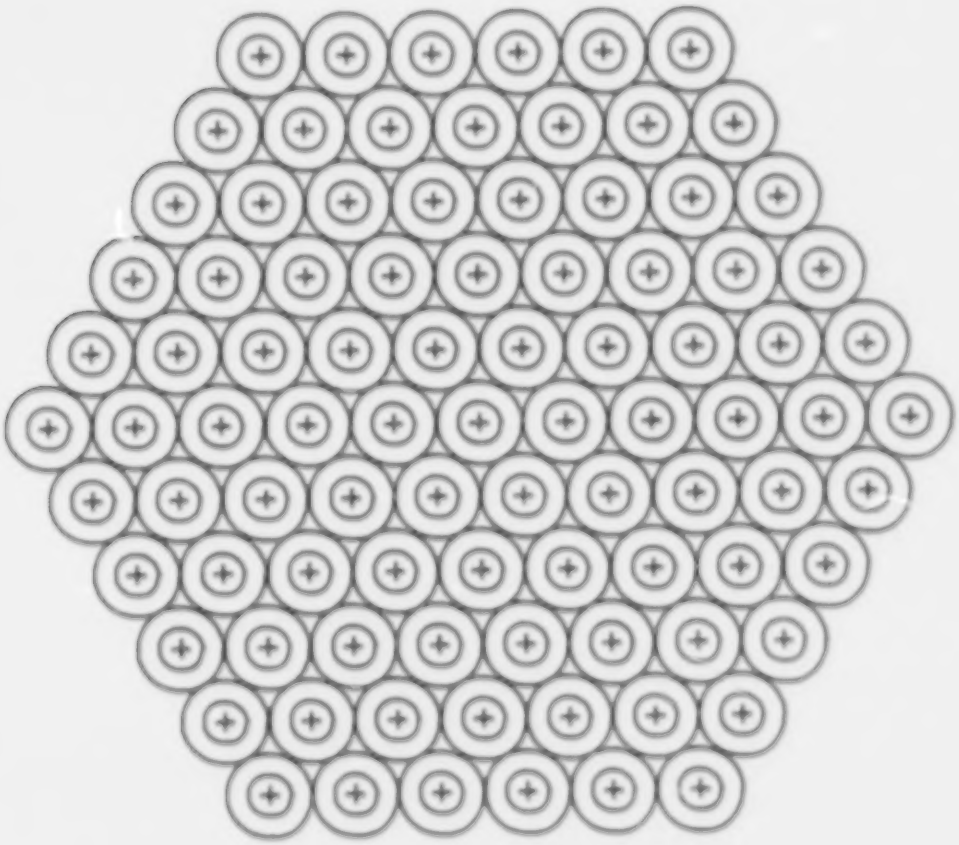
ARRAYPL.FTN

LENS DIAMETER	=	0.29450
NUMBER OF DIODES	=	127.
θ	=	10°

CMLENS.FTN

UNITS = INCHES & DEGREES

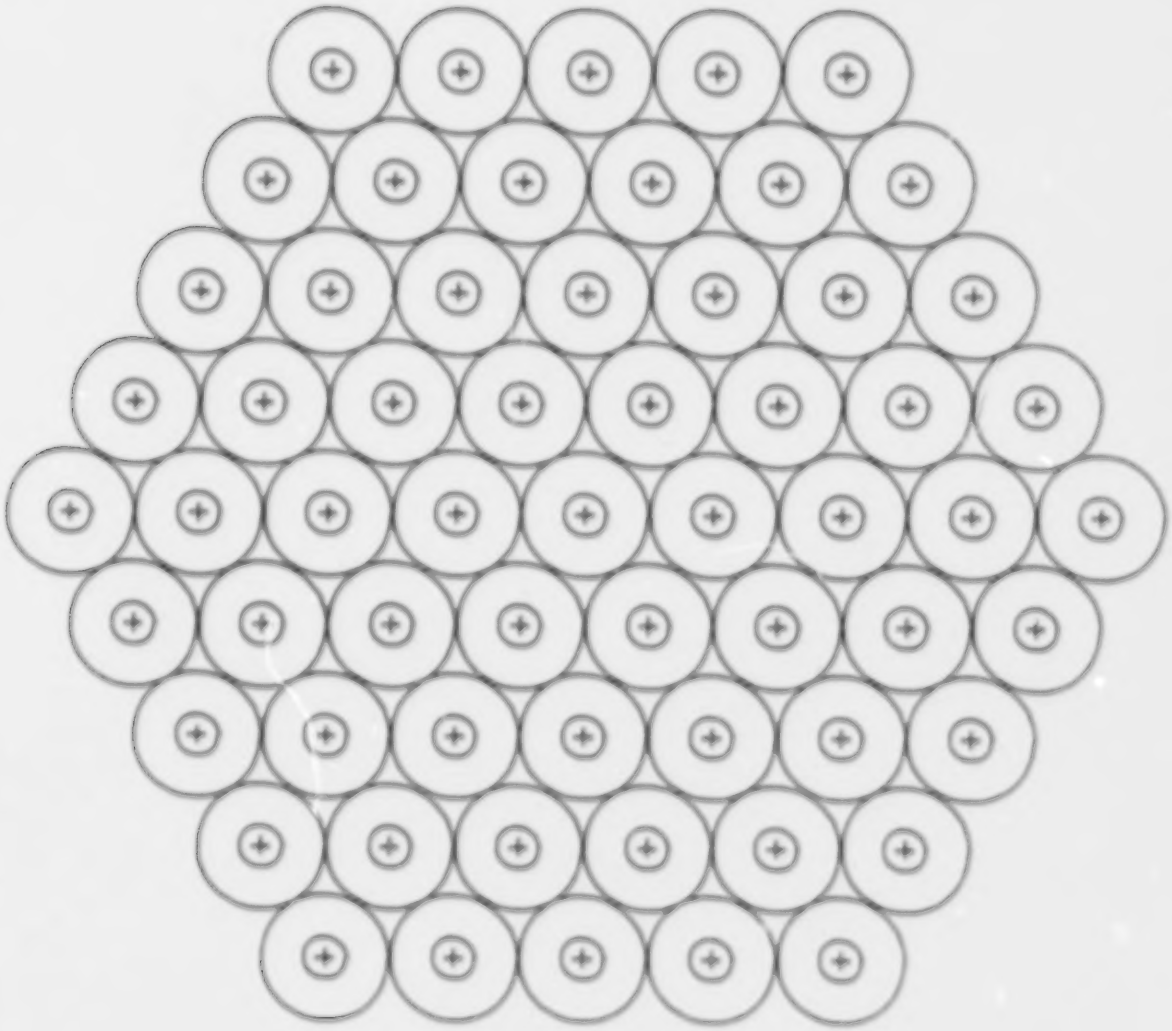
DISPERSION ANGLE	=	10.00000
SOURCE DIAMETER	=	0.06000
N2	=	1.52000
SOURCE TO VERTEX	=	0.39246
F1F2	=	0.33719
MAJOR AXIS	=	0.44723
MINOR AXIS	=	0.29456
LIGHT COLLECTION ANGLE	=	82.27890



ARRYPL.FTN
LENS DIAMETER = 0.49417
NUMBER OF DIODES = 91.
θ = 6°

CNLENS.FTN
UNITS = INCHES & DEGREES

DISPERSION ANGLE	=	6.00000
SOURCE DIAMETER	=	0.06000
N2	=	1.52000
SOURCE TO VERTEX	=	0.65841
F1F2	=	0.56569
MAJOR AXIS	=	0.75113
MINOR AXIS	=	0.49417
LIGHT COLLECTION ANGLE	=	82.27890



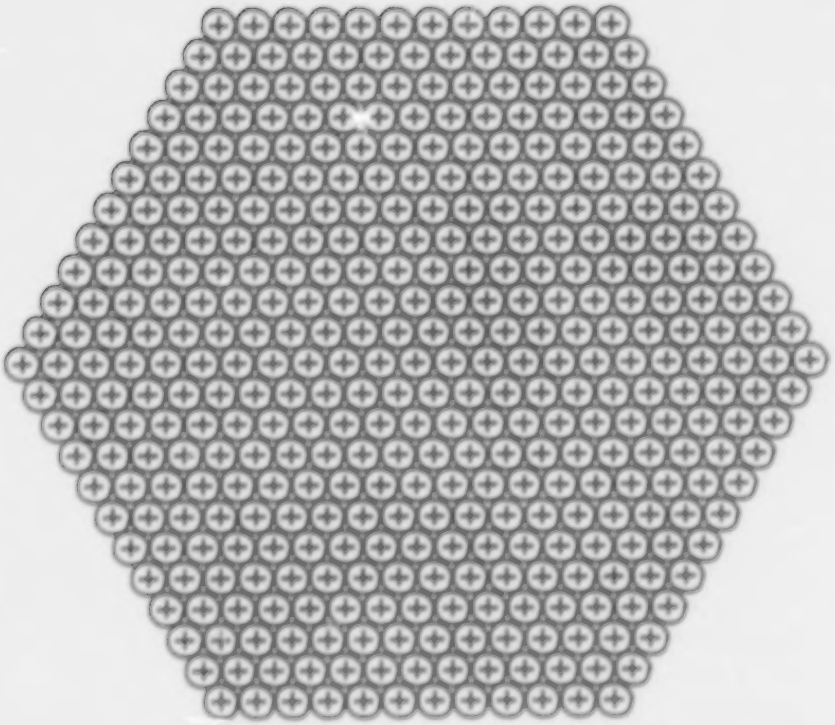
ARRYPL.FTN

LENS DIAMETER	=	0.74270
NUMBER OF DIODES	=	61.
θ	=	4°

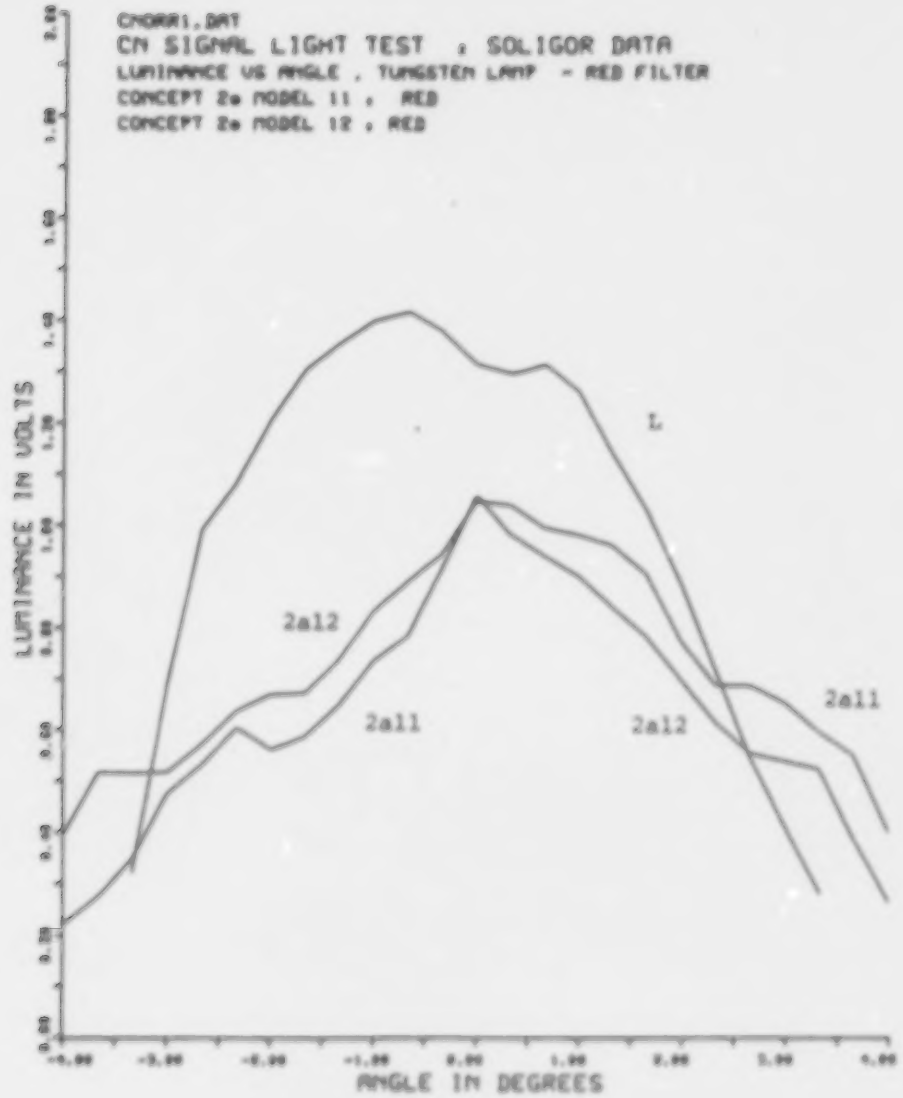
CNLENS.FTN

UNITS = INCHES & DEGREES

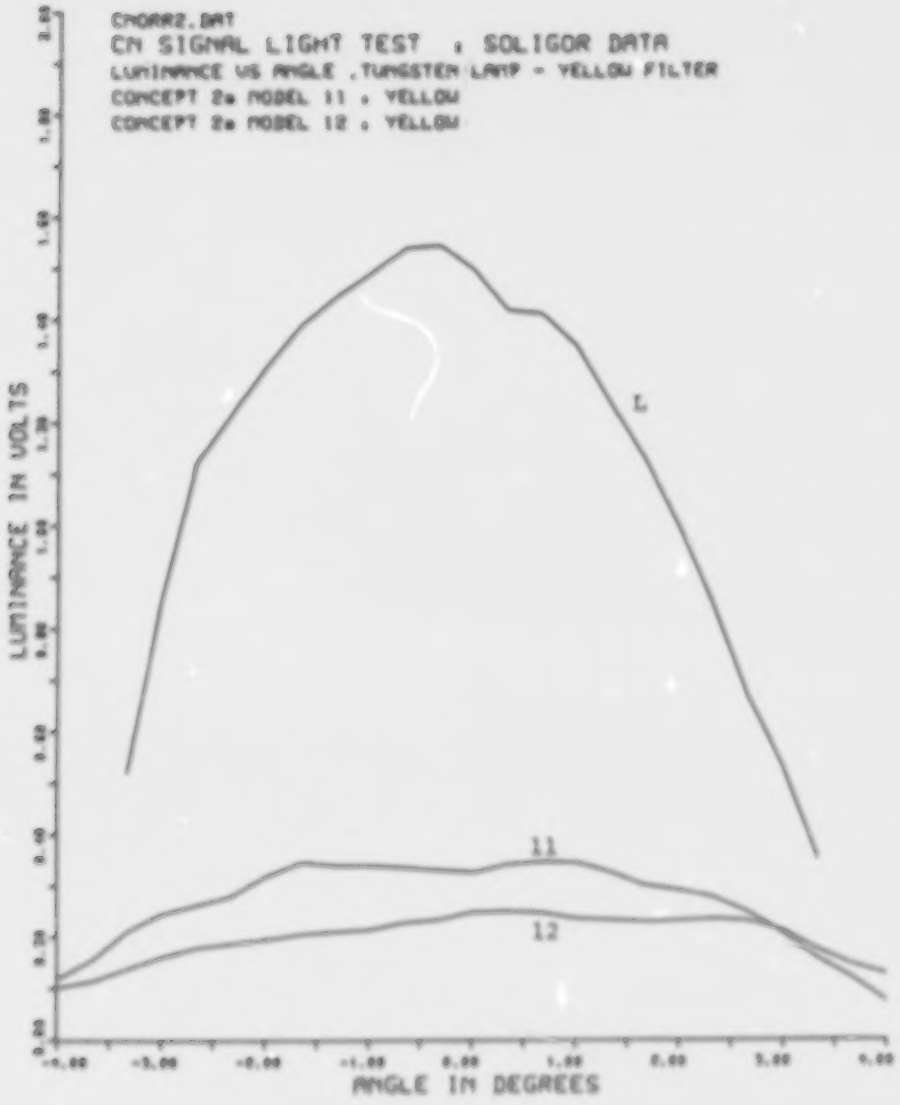
DISPERSION ANGLE	=	4.00000
SOURCE DIAMETER	=	0.06000
N2	=	1.52000
SOURCE TO VERTEX	=	0.98963
F1F2	=	0.85026
MAJOR AXIS	=	1.12900
MINOR AXIS	=	0.74276
LIGHT COLLECTION ANGLE	=	82.27890



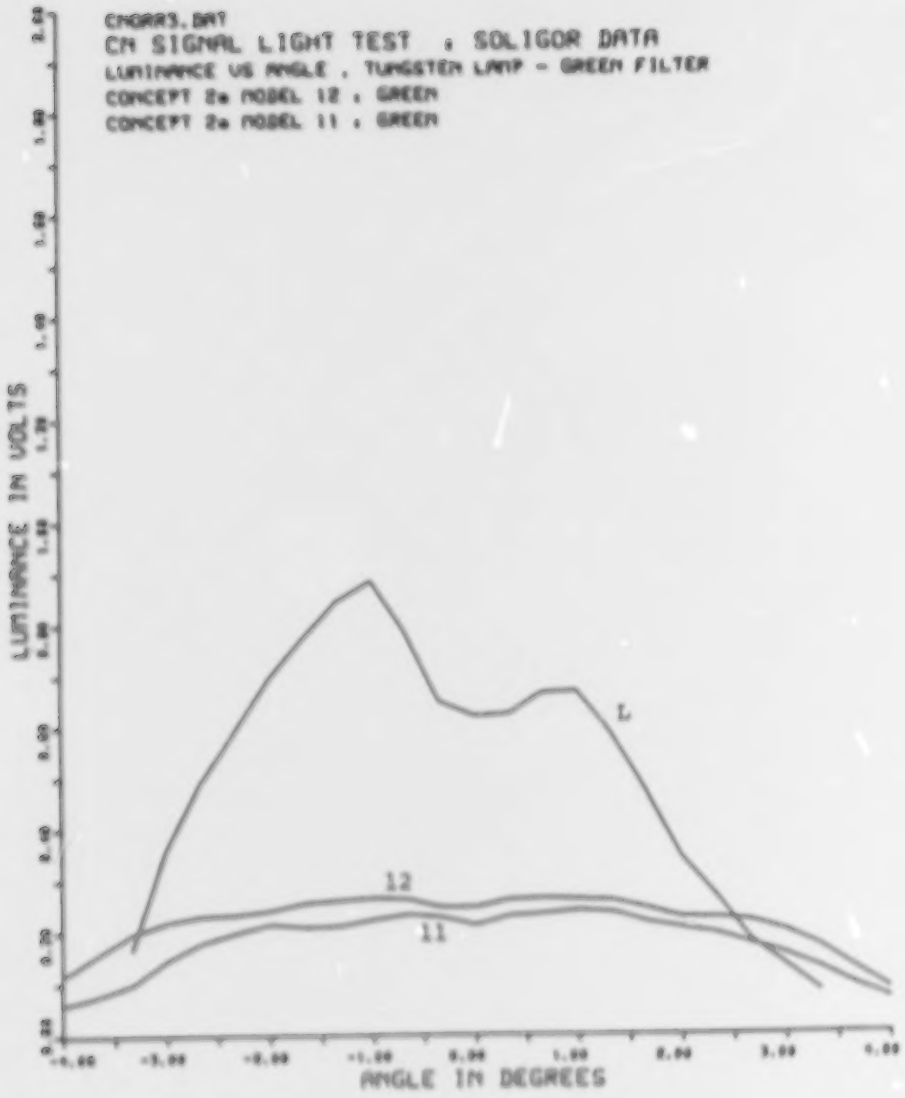
ARRAYD1.FTN
LENS DIAMETER = 0.20500
NUMBER OF DIODES = 397.
α = 12° - 24°


CHORR1.DAT
CN SIGNAL LIGHT TEST : SOLIGOR DATA
LUMINANCE VS ANGLE , TUNGSTEN LAMP - RED FILTER
CONCEPT Ze MODEL 11 : RED
CONCEPT Ze MODEL 12 : RED
LUMINANCE IN VOLTS
ANGLE IN DEGREES
L
2a12
2a11
2a12
2a11

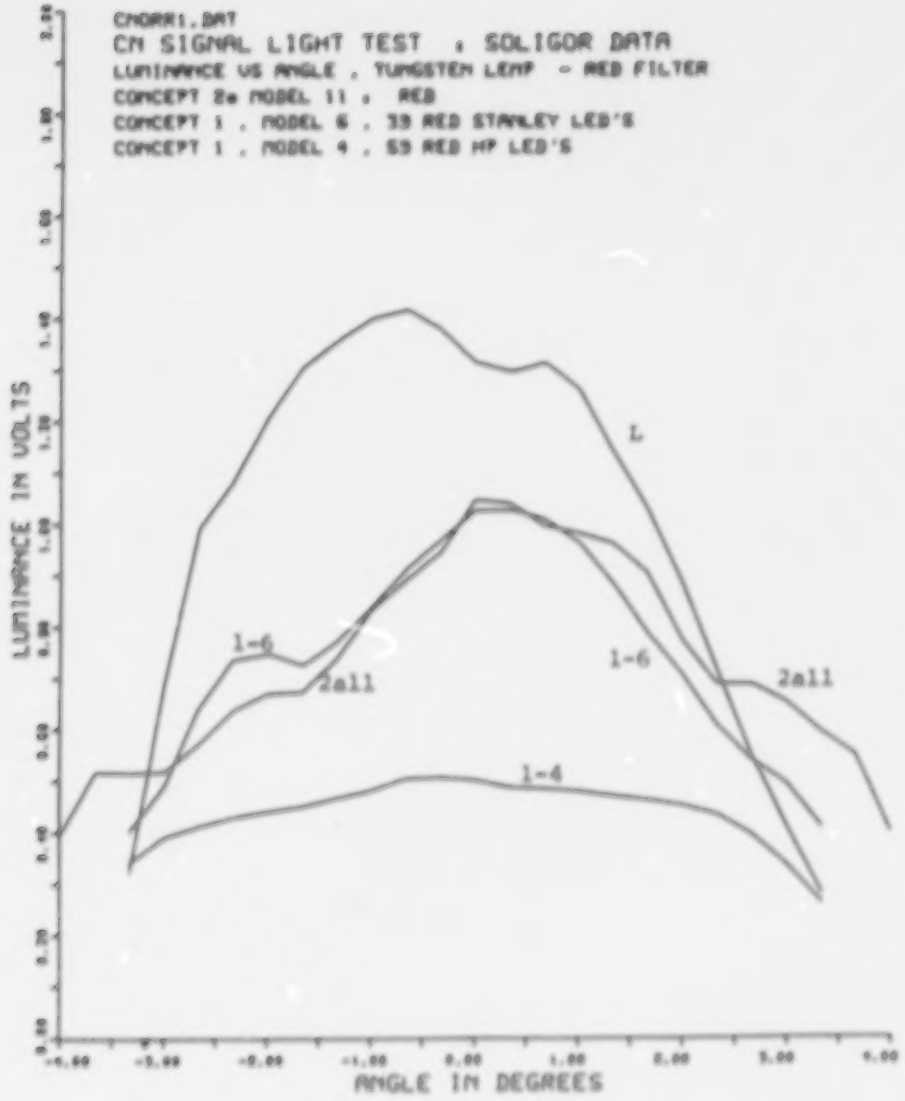
PLOT #8


CHORR2.DAT
CN SIGNAL LIGHT TEST : SOLIGOR DATA
LUMINANCE VS ANGLE ,TUNGSTEN LAMP - YELLOW FILTER
CONCEPT 2a MODEL 11 : YELLOW
CONCEPT 2a MODEL 12 : YELLOW
LUMINANCE IN VOLTS
ANGLE IN DEGREES
L
11
12

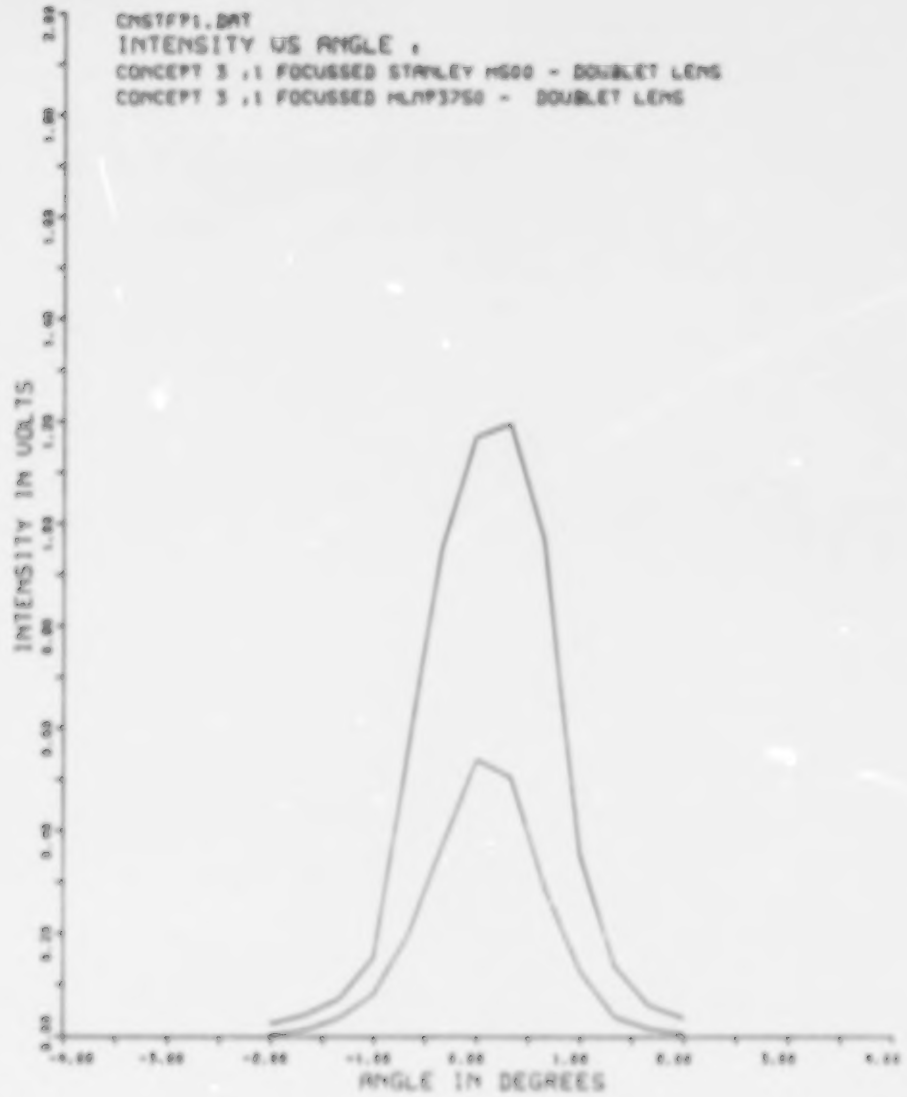
PLOT #9


CHORR3.DAT
CH SIGNAL LIGHT TEST : SOLIGOR DATA
LUMINANCE VS ANGLE , TUNGSTEN LAMP - GREEN FILTER
CONCEPT 2a MODEL 12 : GREEN
CONCEPT 2a MODEL 11 : GREEN
LUMINANCE IN VOLTS
ANGLE IN DEGREES
L
12
11

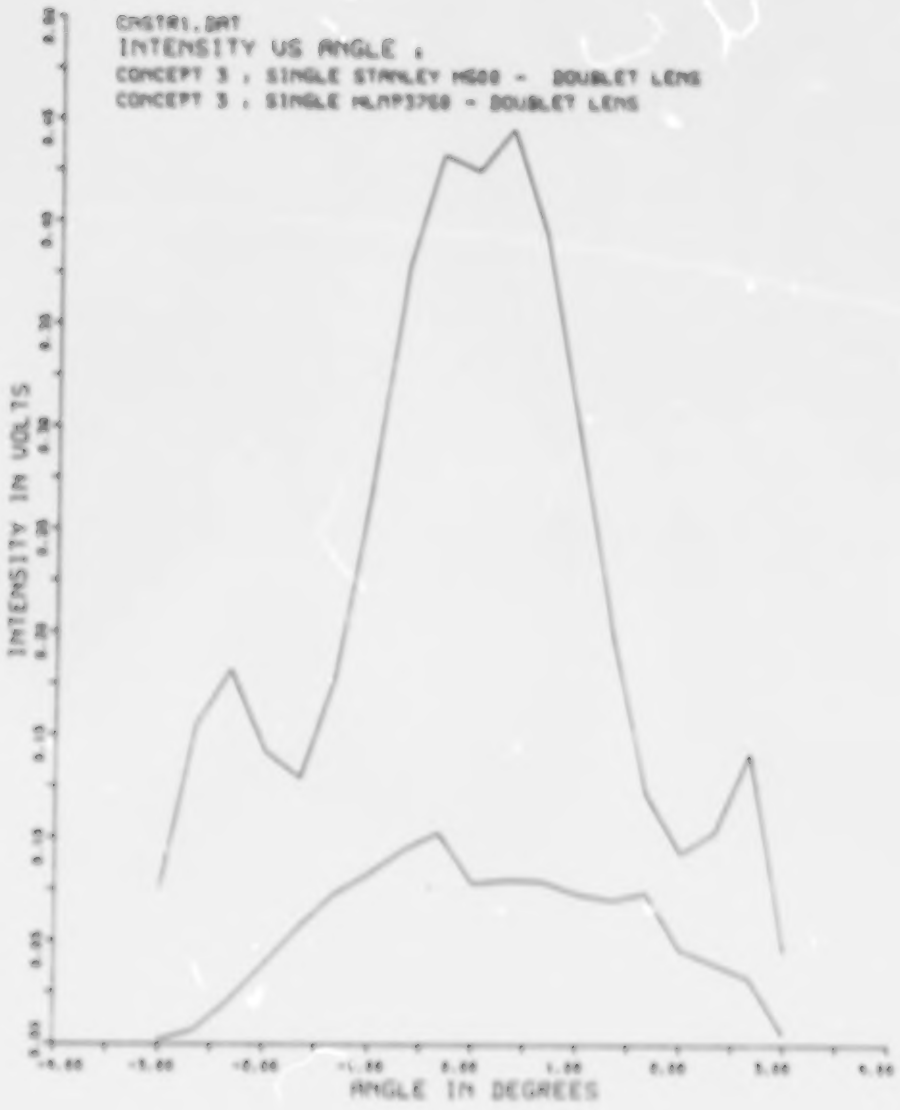
PLOT #10


CHORR1.DAT
CH SIGNAL LIGHT TEST , SOLIGOR DATA
LUMINANCE VS ANGLE , TUNGSTEN LAMP - RED FILTER
CONCEPT 2a MODEL 11 , RED
CONCEPT 1 , MODEL 6 , 33 RED STANLEY LED'S
CONCEPT 1 , MODEL 4 , 69 RED HP LED'S
LUMINANCE IN VOLTS
ANGLE IN DEGREES
L
1-6
2all
1-6
2all
1-4

PLOT 811


CNS7FP1.DAT
INTENSITY VS ANGLE ,
CONCEPT 3 ,1 FOCUSSED STANLEY M500 - DOUBLET LENS
CONCEPT 3 ,1 FOCUSSED MLMP3750 - DOUBLET LENS
INTENSITY IN VOLTS
ANGLE IN DEGREES

PLOT 12


CMSTR1.DAT
INTENSITY VS ANGLE :
CONCEPT 3 : SINGLE STANLEY M600 - DOUBLET LENS
CONCEPT 3 : SINGLE MAP3760 - DOUBLET LENS
INTENSITY IN VOLTS
ANGLE IN DEGREES

PLOT 13

APPENDIX B

LED SUPPLIERS LIST
LED Specification Sheets

- Stanley H500
- Data Display 200-Uxx
- OSRINO OLSR 150, OLUR 15x
- General Inst. MV5xxx
- Toshiba TLUX 153
- HP HLMP 350
- Fairchild FLV104A
- Stanley ESBX5501

Davis Engineering
Consulting Engineers

October 3, 1983

DE File No: C83-81

JKL Components Corp.
2226 Barry Avenue,
Los Angeles, C.A. 90064

Dear Sirs,

We are in the prototype stage of designing a low power three colour signal/light and are testing the suitability of LEDs as the light source. We are in need of any product information you may have concerning high brightness LEDs. In particular, red, yellow and green LEDs with non diffused (clear) lenses, and a narrow beam width.

We are also interested in the manufacturing possibilities for:

- LED arrays, i.e. 2 or more chips under the same lense to achieve higher brightness and intensity;
- lenses to produce a narrow angle beam width if not possible using existing lenses; and,
- the ability to produce LEDs of certain colours (especially pure green and pure yellow) and/or the availability of filters to alter the chromaticity of existing LEDs.

Any product samples that you feel we might be interested in would also be greatly appreciated.

Yours truly,

Ian Wyatt

Ian Wyatt
Engineer

IW/cs

STANLEY HI-SUPER BRIGHT LEDs

Profile

Stanley Electric Co., Ltd., founded in 1920, has grown to be one of the leading companies in Japan's lighting industry, specialized in semiconductors, electric equipment, motor vehicle light bulbs, lighting equipment, and other electronic products. The company's development has been characterized by an emphasis on technological advancement in selected areas.

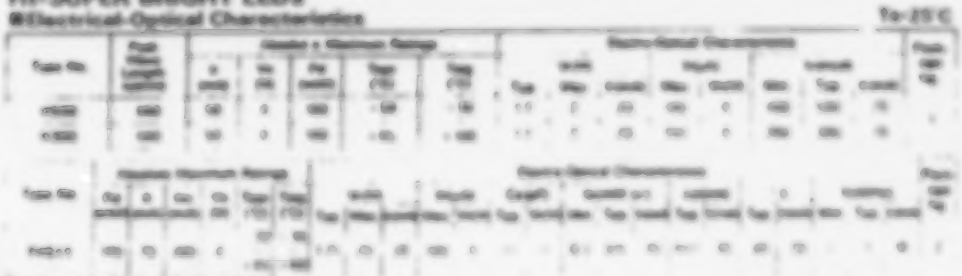
Stanley LEDs have been developed with the technical support by Dr., Prof., Juni-ichi Nishizawa of Tohoku University and under an assignment made by Research Development Corporation of Japan.

INDEX

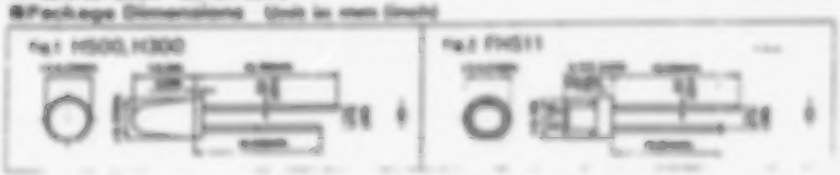
- HI-SUPER BRIGHT LEDs (H500, H300, FH511) ..... P. 1
- SUPER BRIGHT LEDs (SBR2301, 3401 others) ..... P. 2 ~ P. 4
- SUPER BRIGHT LED SEVEN SEGMENT DISPLAYS (NSR161, NSR163 others) ..... P. 5 ~ P. 6
- SUPER BRIGHT LED LIGHT BAR (NSBL05 SBU Series, SU Series) ..... P. 7 ~ P. 9
- SUPER BRIGHT 2-CHIP LED (PHR302) ..... P. 10
- INFRARED LEDs (SIR101, 3103 others) ..... P. 10
- PHOTOTRANSISTORS (PS101, PS103 others) ..... P. 11

HI-SUPER BRIGHT LEDs

●Electrical-Optical Characteristics Ta=25°C



●Package Dimensions Unit in mm (inch)



●Forward Current vs Relative Luminous Intensity

●Forward Current Degrading Curve

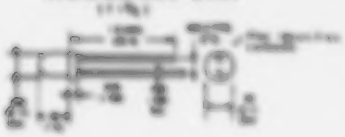
●Ambient Temperature vs Forward Current Capability

●Forward Voltage vs Forward Current

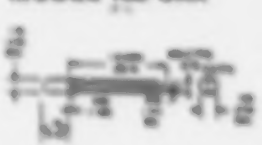
[illegible]

P.O. Box [illegible], Los Angeles, CA [illegible] • [illegible] • Telex [illegible]

MODEL 200-UXX



MODEL 125-UXX



Tolerances [illegible]

ABSOLUTE MAXIMUM RATINGS

@ TA = 25° C

Power Dissipation [illegible] 120mW

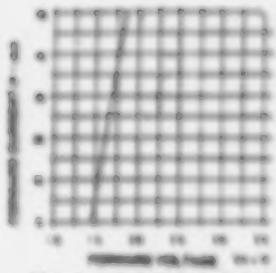
Derate 1.6mW/°C above 25°C ambient

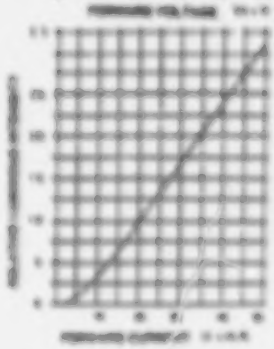
Forward Current [illegible] 50mA (red)
40mA (others)

Peak Forward Current [illegible] 100mA
@ 1% Duty cycle

Operating &
Storage Temp [illegible] -55° to +100°C

Lead Soldering Temp [illegible] 260°C for 5 sec
(1/16" below any base)





**TYPICAL OPERATING CHARACTERISTICS @ 25° C AMBIENT, IF = 50 mA (red)
40 mA (others)**

	SYM.	MIN.	RED		AMBER		YELLOW		GREEN		UNITS
			TYP.	MAX.	TYP.	MAX.	TYP.	MAX.	TYP.	MAX.	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
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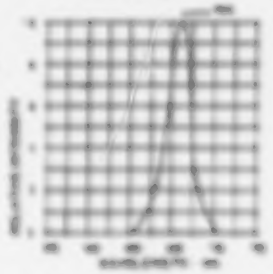
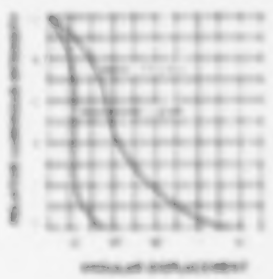




OSRAM

SUPER BRIGHT LEDs

Package Number / Lens Drop (Dia. Inch)	Part Number	Lens Color	Chip Color	Peak Emission Wavelength (nm)	Maximum Ratings (Ta = 25°C)					Electro-optical Data (Ta = 25°C)					
					I_F (mA)	V_R (V)	P_D (mW)	T_{opr} (°C)	T_{stg} (°C)	V_F (V) Typ/Max	I_F (mA)	I_R (μA) Max	V_R (V)	τ_r (nsec) Typ	τ_f (nsec)
1	OLSR-163		RED	635	50	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	40	40
	OLSR-164													40	40
	OLSG-163		GREEN	565	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	5	4	20	20
	OLSG-164													10	20
	OLSY-163		YELLOW	585	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	20	20
	OLSY-164													10	20
	OLSO-163		ORANGE	610	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	20	20
1 x 1	OLSO-164													10	20
1	OLSR-133		RED	635	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	10	20
1 x 1 WIDE VIEWING ANGLE	OLSR-134													6	20
1	OLSR-140*		RED	635	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	100	20
	OLSR-143													60	20
	OLSR-144													30	20
	OLSG-143		GREEN	565	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	5	4	20	20
	OLSG-144													10	20
1 x 1 x LOW PROFILE	OLSY-143		YELLOW	585	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	20	20
	OLSY-144													10	20
1	OLSR-153		RED	635	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	100	20
	OLSR-154													50	20
	OLSG-153		GREEN	565	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	5	4	20	20
	OLSG-154													10	20
	OLSY-153		YELLOW	585	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	20	20
	OLSY-154													10	20
	OLSO-153		ORANGE	610	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	20	20
	OLSO-154													10	20
1 x 1 x	OLSR-150*		RED	635	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	100	20
1	OLSR-113		RED	635	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	20	20
1 x 1 x WIDE VIEWING ANGLE	OLSR-114													10	20
1	OLSG-113		GREEN	565	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	5	4	20	20
	OLSG-114													10	20
1 x 1 x	OLSY-113		YELLOW	585	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	20	20
	OLSY-114													10	20
1 x 1 x	OLSO-113		ORANGE	610	25	4	70	0 to 70	-30 to +100	2.1/2.6	20	100	4	20	20
	OLSO-114													10	20

Evaluation Factory for availability

ULTRA BRIGHT LEDs

Outline Number Lens Type (Clear, Diff)	Part Number	Lens Color	Chip Color	Peak Emission Wavelength (nm)	Maximum Ratings (T_A = 25°C) I_F (mA)	V_R (V)	P_D (mW)	T_{OPR} (°C)	T_{STG} (°C)	Electrical and Optical Characteristics (T_A = 25°C) V_F (V) Typ	Max	I_R (μA) Max	V_R (V)	I_V (mcd) T_{YP}	Min
1	OLUR-163		RED	660	35	4	85	-30 to +75	-30 to +100	1.7 to 2.5	3.0	100	4	45	30
	OLUR-164													30	20
	OLUG-163		GREEN	565	35	4	75	-30 to +75	-30 to +100	2.1 to 3.8	3.0	10	4	45	30
	OLUG-164													30	20
	OLUY-163		YELLOW	585	35	4	75	-30 to +75	-30 to +100	2.1 to 3.8	3.0	100	4	45	30
2	OLUY-164													30	20
1	OLUR-123		RED	660	35	4	85	-30 to +75	-30 to +100	1.7 to 2.5	3.0	100	4	30	20
2 WIDE VIEWING ANGLE	OLUR-124													15	10
1	OLUR-143		RED	660	35	4	85	-30 to +75	-30 to +100	1.7 to 2.5	3.0	100	4	120	80
	OLUR-144													60	40
	OLUG-143		GREEN	565	35	4	75	-30 to +75	-30 to +100	2.1 to 3.8	3.0	10	4	60	40
	OLUG-144													30	20
	OLUY-143		YELLOW	585	35	4	75	-30 to +75	-30 to +100	2.1 to 3.8	3.0	100	4	80	60
1 1.4 x LED PROFILE	OLUY-144													40	30
	OLUR-140[1]		RED	630	30	4	80	-30 to +75	-30 to +100	2.1 to 3.8	3.0	100	4	150	100
1	OLUR-153		RED	660	35	4	85	-30 to +75	-30 to +100	1.7 to 2.5	3.0	100	4	200	150
	OLUR-154													100	80
	OLUG-153		GREEN	565	35	4	75	-30 to +75	-30 to +100	2.1 to 3.8	3.0	10	4	100	80
	OLUG-154													60	40
	OLUY-153		YELLOW	585	35	4	75	-30 to +75	-30 to +100	2.1 to 3.8	3.0	100	4	120	80
	OLUY-154													80	60
1 1.4 x	OLUR-150		RED	660	30	4	80	-30 to +75	-30 to +100	2.1 to 3.8	3.0	100	4	200	150
2	OLUR-113		RED	660	35	4	85	-30 to +75	-30 to +100	1.7 to 2.5	3.0	100	4	30	20
	OLUR-114													15	10
2 1.4 x WIDE VIEWING ANGLE	OLUR-120													22	15
	OLUR-130[1]													70	50

[1] Outline at OLUR-123, p. 4

[2] Consult factory for availability

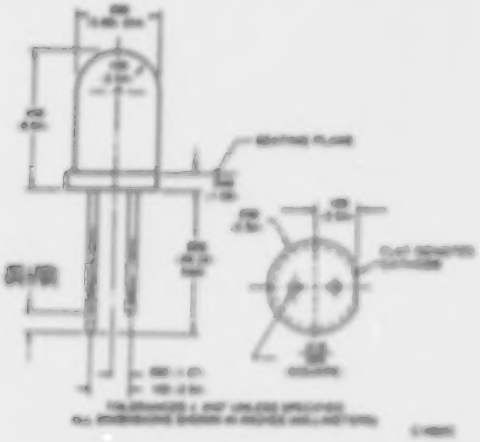
SINGLE CHIP SOLID STATE ILLUMINATOR

GENERAL INSTRUMENT

Optoelectronics Division
3400 Hillview Avenue
Palo Alto, California 94304
(415) 493-0400 — TWX (910) 373-1767

HI EFF. RED **MK9160**
YELLOW **MK9360**

PACKAGE DIMENSIONS



DESCRIPTION

These advanced light emitting diode lamps provide the combination of high on-axis luminous intensity and wide viewing angle from a single LED emitter chip. These lamps are capable of providing [illegible] with a forward current of 100 mA. The LED chip is a high efficiency GaAsP/GaP emitting a peak wavelength of 635 nm (MK9160) and [illegible] nm (MK9360). Clear lens. Anode long

ABSOLUTE MAXIMUM RATINGS

Power Dissipation @ 25°C lead temperature	[illegible] mW
Storage Temperature	-40°C to +100°C
Operating Temperature	-40° to +85°C
Lead Solder Time @ 260°C	5 sec.
Continuous Forward Current @ 25°C lead temperature	100 mA
Continuous Forward Current @ 70°C lead temperature	50 mA
Peak Forward Current	1 C.A
Reverse Voltage	5 volts
Maximum Diode Junction Temperature (T_J)	90°C

[illegible]

AL OPERATING CHARACTERISTICS at 25°C

METER	SYMBOL	TYPICAL	UNIT	TEST CONDITION
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

ULTRA BRIGHT LAMP

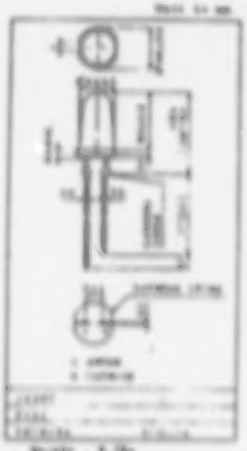
TLUR153, TLUR154

GaAlAs RED LIGHT EMISSION

5mm DIAMETER(T 1 3/4)

Features

- Ultra-bright
- All Plastic Mold Type
  TLUR153 : Light Red Transparent Lens
  TLUR154 : Light Red Submarine Lens
- Low Drive Current, High Luminosity Red Light Emission
  Recommended Forward Current : I_F=10 mA(DC)
- All Plastic Molded Lens, Provides an Excellent On-Off Emission Ratio
- Fine Reference Type, Capable of Pulse Operation

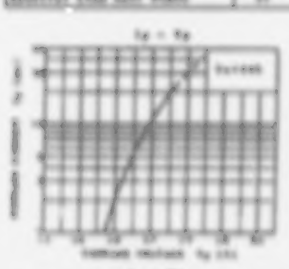


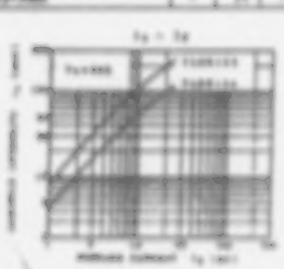
MAXIMUM RATINGS (T_a =25°C)

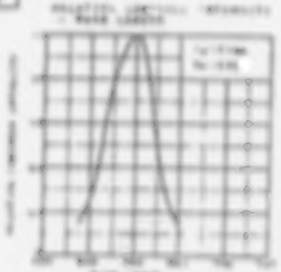
Characteristics	Symbol	Ratings	Unit
Forward Current (DC)	I_F	25	mA
Reverse Voltage	V_R	5	V
Power Dissipation	P_D	75	mW
Operating Temperature Range	T_{OPR}	-25 ~ 75	°C
Storage Temperature Range	T_{STG}	-30 ~ 100	°C

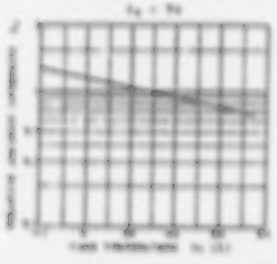
ELECTRO-OPTICAL CHARACTERISTICS (T_a =25°C)

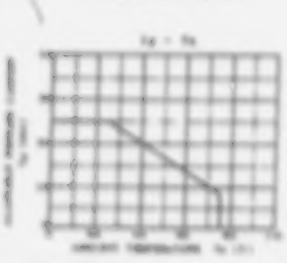
Characteristics		Symbol	Test Condition	min	typ	max	Unit
Forward Voltage		V_F	I_F=20mA	-	1.75	2.2	V
Reverse Current		I_R	V_R=5V	-	-	100	μA
Luminous Intensity	TLUR153	I_V	I_F=20mA	50	200	-	mcd
	TLUR154			25	100	-	
Peak Emission Wave Length		λ_P	I_F=20mA	-	660	-	nm
Spectrum Line Half Width		$\Delta\lambda$	I_F=20mA	-	25	-	nm

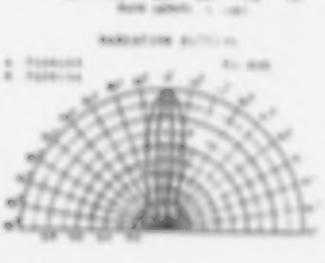












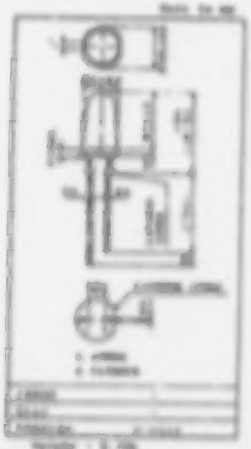
ULTRA BRIGHT LAMP

TLUG153, TLUG154

GaP GREEN LIGHT EMISSION

5mm DIAMETER T (3/4)

- Colorless
- All Plastic Solid Type
  TLUG153 : Light source Transparent Lens
  TLUG154 : Light Green Colored Diffuse Lens
- Low Drive Current, High Luminous Green Light Emission
  Recommended Forward Current : IF=10 (Max.20)
- All Plastic Molded Lens, Precise Optical Alignment
- Fast Response Time, Capable of Pulse Operation

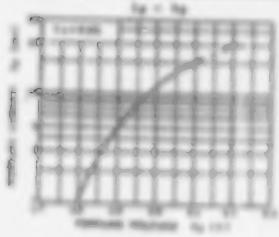


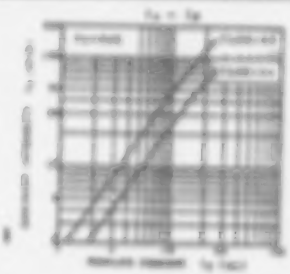
MAXIMUM RATINGS (Ta =25°C)

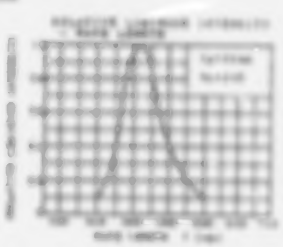
Characteristics	Symbol	Ratings	Unit
Forward Current (DC)	IF	25	mA
Reverse Voltage	VR	5	V
Power Dissipation	PD	75	mW
Operating Temperature Range	Topr	-25 ~ 75	°C
Storage Temperature Range	Tstg	-30 ~ +100	°C

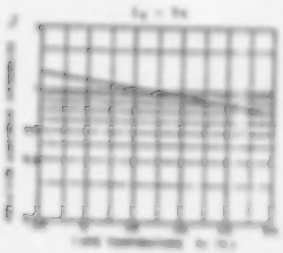
ELECTRO-OPTICAL CHARACTERISTICS (Ta =25°C)

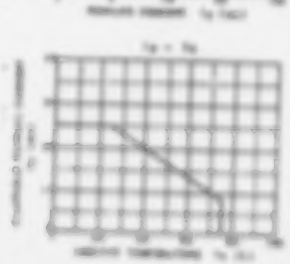
Characteristics		Symbol	Test Condition	min.	typ.	max.	Unit
Forward Voltage		VF	IF=20mA	-	2.1	2.6	V
Reverse Current		IR	VR=5V	-	-	5	μA
Luminous Intensity	TLUG153	IV	IF=10mA	40	125	-	mcd
	TLUG154			25	80	-	
Peak Emission Wave Length		λp	IF=20mA	-	565	-	nm
Spectrum Line Half Width		Δλ	IF=20mA	-	25	-	nm

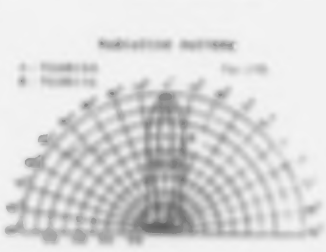












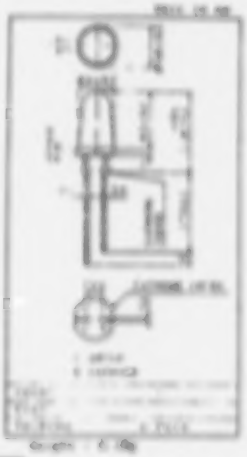
ELECTRONIC COMPONENTS OPERATION
A BUSINESS SECTION OF CANADIAN GENERAL ELECTRIC COMPANY LIMITED TELEPHONE (416) 828-0740

ULTRA BRIGHT LAMP

TLUY153, TLUY154

GaAsP YELLOW LIGHT EMISSION

5mm DIAMETER T 13/4

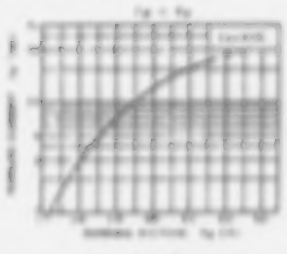


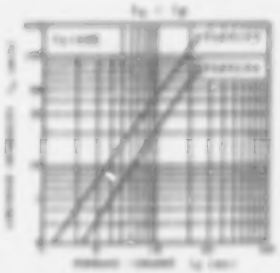
MAXIMUM RATINGS (Ta =25°C)

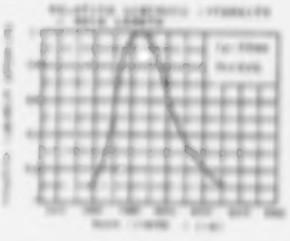
CHARACTERISTIC	SYMBOL	RATING	UNIT

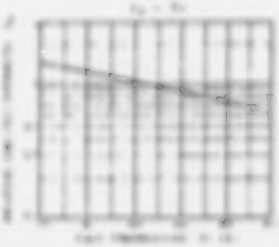
ELECTRO-OPTICAL CHARACTERISTICS (Ta =25°C)

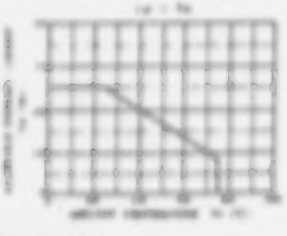
CHARACTERISTIC		SYMBOL	TEST CONDITION	MIN.	TYP.	MAX.	UNIT

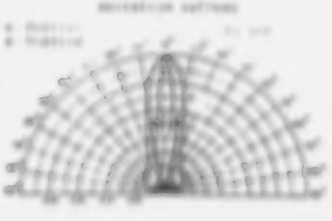










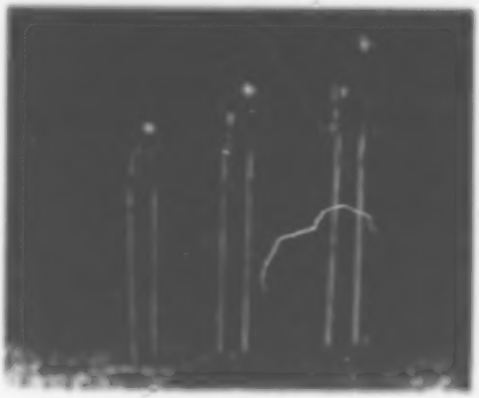


ELECTRONIC COMPONENTS OPERATION
A DIVISION OF TOSHIBA CORPORATION GENERAL ELECTRIC COMPANY LIMITED TELEPHONE

TECHNICAL DATA JANUARY 1

Features

- IMPROVED BRIGHTNESS
- IMPROVED COLOR PERFORMANCE
- AVAILABLE IN POPULAR T-1 and T-1 3/4 PACKAGES
- NEW STURDY LEADS
- IC COMPATIBLE/LOW CURRENT CAPABILITY
- RELIABLE AND RUGGED
- CHOICE OF 3 BRIGHT COLORS
  High Efficiency Red
  High Brightness Yellow
  High Performance Green



Description

These clear, non-diffused lamps out perform conventional LED lamps. By utilizing new higher intensity material, we achieve superior product performance.

The HLMP-D150-D3B0-1540 Series Lamps are Gallium Arsenide Phosphide on Gallium Phosphide red light emitting diodes. The HLMP-3850-3480-1440 Series are Gallium Arsenide Phosphide on Gallium Phosphide yellow light emitting diodes. The HLMP-3950-3580-1540 Series lamps are Gallium Phosphide green light emitting diodes.

Applications

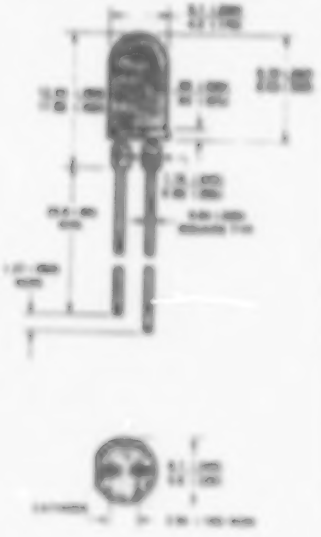
- LIGHTED SWITCHES
- BACKLIGHTING FRONT PANELS
- LIGHT PIPE SOURCES
- KEYBOARD INDICATORS

Axial Luminous Intensity and Viewing Angle @ 25°C

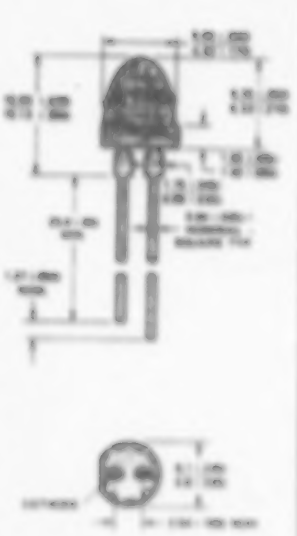
Part Number HLMP-	Package Description	Color	I_V (mcd) @ 20 mA DC Min.	Typ.	2θ 1/2 Note 1.	Package Outline
[illegible]	T-1 3/4	[illegible]	60	120	24°	A
[illegible]	T-1 3/4	[illegible]	60	140	24°	A
[illegible]	T-1 3/4	[illegible]	60	130	24°	A
[illegible]	T-1	[illegible]	35	80	32°	B
[illegible]	T-1	[illegible]	35	95	32°	B
[illegible]	T-1	[illegible]	35	85	32°	B
[illegible]	T-1	[illegible]	[illegible]	35	48°	C
[illegible]	T-1	Yellow	[illegible]	35	48°	C
[illegible]	T-1	Green	35	80	48°	C

Notes:
1. $\theta_{1/2}$ is the typical off-axis angle at which the luminous intensity is half the axial luminous intensity.

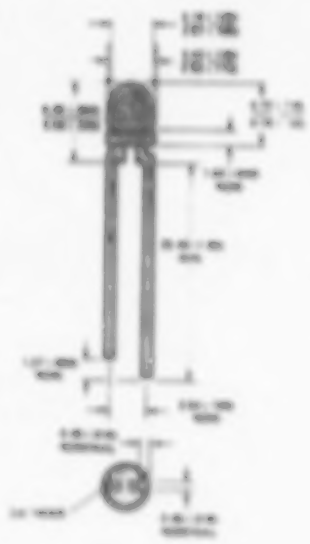
Package Dimensions



PACKAGE OUTLINE 'A'



PACKAGE OUTLINE 'B'



PACKAGE OUTLINE 'C'

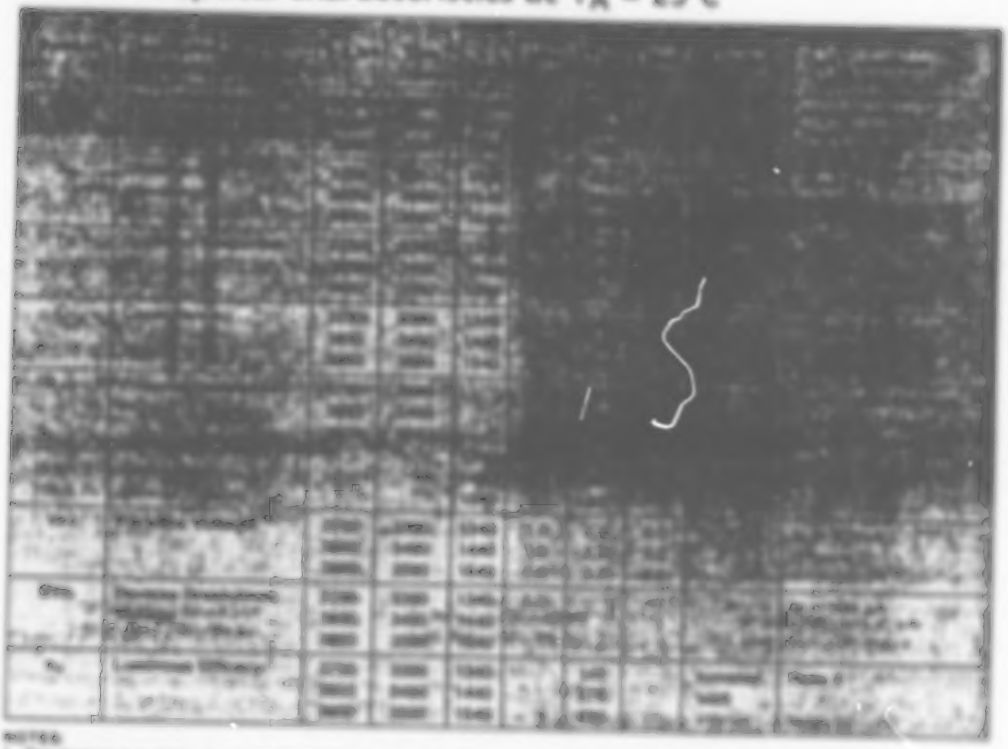
NOTES:
1. All dimensions are in millimeters (inches).
2. Epoxy meniscus may extend about 1mm (.040") down the leads.

Absolute Maximum Ratings at T_A = 25°C

Parameter	Red	Yellow	Green	Units
Peak Forward Current	90	90	90	mA
Average Forward Current[1]	25	25	25	mA
DC Current[2]	30	30	30	mA
Power Dissipation[2]	135	90	135	mW
Operating and Storage Temperature Range	-40°C to +100°C			
Lead Soldering Temperature [1.6 mm (0.063 in.) from Body]	260°C for 5 seconds			

NOTES:
1. See Figure 2 to establish pulsed operating conditions.
2. For Red and Green series derate linearly from 50°C at 0.5 mA /°C. For Yellow series derate linear... from 50°C at 0.2 mA /°C.
3. For Red and Green series derate power linearly from 25°C at 1.8 mW /°C. For Yellow series de... power linearly from 50°C at 1.6 mW /°C.

Electrical/Optical Characteristics at T_A = 25°C



NOTES:
1. The dominant wavelength, λ_d, is derived from the CIE chromaticity diagram and represents the single wavelength which defines the color of the device.
2. Radiant intensity, I_e, in watts/steradian, may be found from the equation $I_e = I_v / \eta_v$, where I_v is the luminous intensity in candelas and η_v is the luminous efficacy in lumens/watt.

Red, Yellow and Green

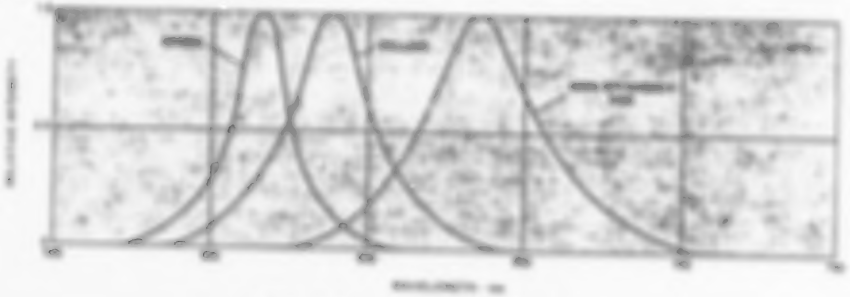


Figure 1. Relative Intensity vs. Wavelength.

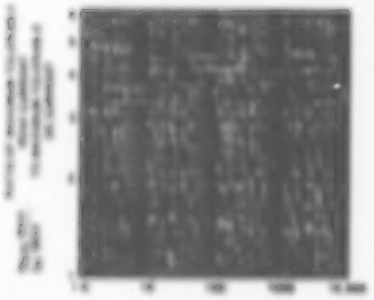


Figure 1. Maximum Tolerable Peak Current vs. Pulse Duration. (Not to be used for Multiple Ratings.)

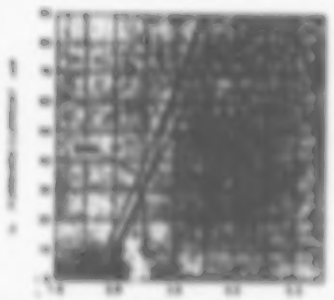


Figure 2. Forward Current vs. Forward Voltage

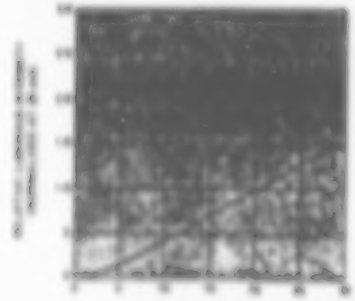


Figure 4. Relative Luminous Intensity vs. Forward Current

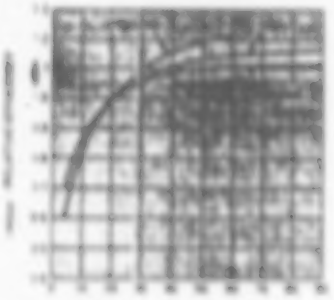


Figure 5. Relative Efficiency (Luminous Intensity per Unit Current) vs. Peak Current

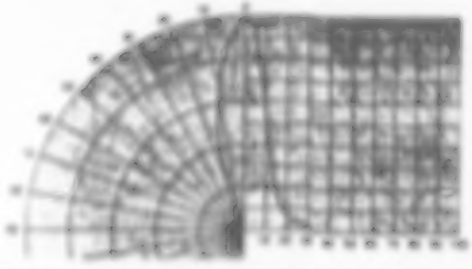


Figure 6. Relative Luminous Intensity vs. Angular Displacement T-1 3/4 Lamp

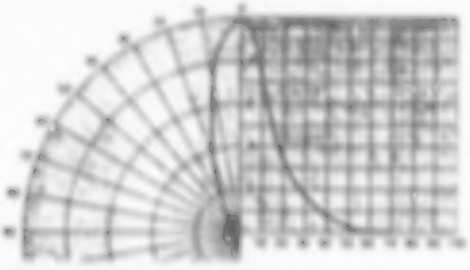


Figure 7. Relative Luminous Intensity vs. Angular Displacement T-1 3/4 Low Profile Lamp

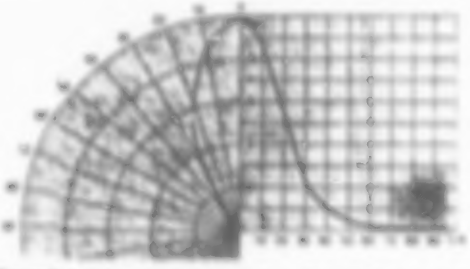


Figure 8. Relative Luminous Intensity vs. Angular Displacement T-1 Lamp

FLV104A
NARROW BEAM GaAsP LAMP
OPTOELECTRONICS PRODUCT GROUP

GENERAL DESCRIPTION — The FLV104A narrow beam visible lamp is a high intensity source specifically intended for excitation of photosensors, especially photo-diodes and transistors, when the separation distances are measured from mm to several meters.

The FLV104A is the visible beam companion device to the FPE104 infrared LED. Both devices have identical optics and therefore identical radiation patterns.

- HIGH [illegible] INTENSITY
- NARROW BEAM[illegible]
- MATCHABLE AT 50 FEET

ABSOLUTE MAXIMUM RATINGS

Maximum Temperatures and Humidity

Storage Temperature	-55°C to +100°C
Operating Temperature	-55°C to +100°C
Pin Temperature (Soldering, 5 s)	260°C
Relative Humidity at 60°C	90 %

Maximum Power Dissipation

Total Dissipation at T_A = 25°C	200 mW
Derate Linearly from T_A = 25°C	2.6 mW/°C

Maximum Voltages and Currents

V_R	Reverse Voltage	3.0 V
I_F	Forward Current	1.0 A
I_F	Peak Forward Current (100 µs pulsewidth 1% duty cycle)	100 mA

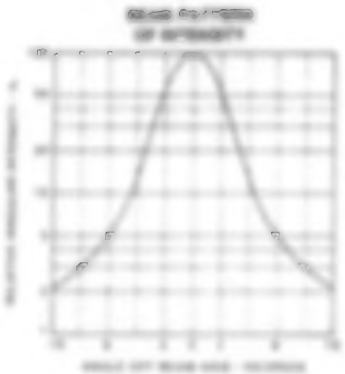
ELECTRICAL CHARACTERISTICS (T_A = 25°C)

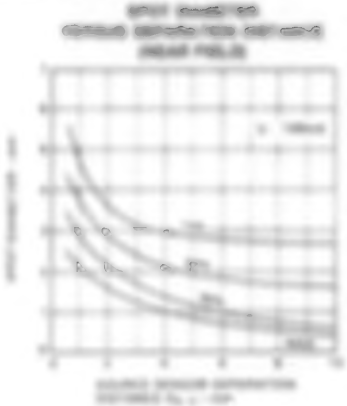
SYMBOL	CHARACTERISTIC	MIN.	TYP.	MAX.	UNITS	TEST COND.
V_F	Forward Voltage		2.0	2.5	Volts	I_F = 100 mA
BV_R	Reverse Breakdown Voltage	3.0	6.0		Volts	I_R = 10 µA

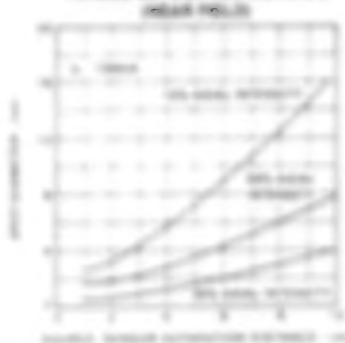
FAIRCHILD • PLESSEY

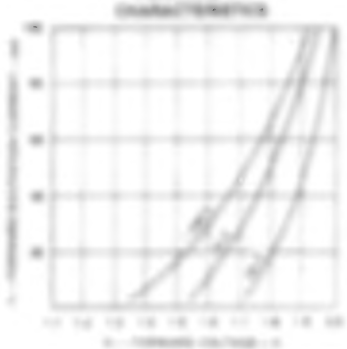
SYMBOL	CHARACTERISTIC	MIN	TYP	MAX	UNITS
I_v	Axial Luminous Intensity	20	100		mcd
I_e	Axial Radiometric Intensity		6.0		mw/sr
L_v	Average Effective Luminance		3.0		apostilb
N_e	Average Effective Radiance (Axial)		1.80		mw/sr/cm²
S_A	Effective Emitting Source Area (Axial)		0.05		cm²
$\Delta I_v/I_v$	Temperature Coefficient of Intensity (Note 1)		0.5		%/°C
$\Delta\lambda_{PE}$	Excitation Coefficient of Intensity (Note 1)		1.0		%/°C
λ_{PE}	Peak Spectral Wavelength		870		nm
$\Delta\lambda$	Spectral Bandwidth		40		nm
$\Delta\lambda_{PE}/\Delta T$	Temperature Spectral Shift Coefficient (Note 2)		0.27		nm/°C
$\Delta\lambda_{PE}/\Delta I_v$	Excitation Spectral Shift Coefficient (Note 2)		0.1		nm/mA
$\theta_{1/2}$	Beam Angle at 50% Axial Intensity		4.5		Degrees
$\Delta\theta_x$	Beam Axis to Mechanical Axis		1.5		Degrees
t_r and t_f	Light Output Rise and Fall Time (Note 3)		10		ns
C_J	Capacitance (V_R=0, f = 1 MHz)		140		pF

TYPICAL CHARACTERISTIC CURVES

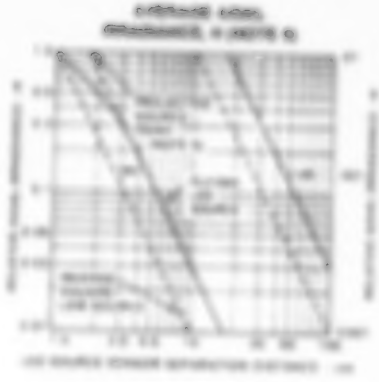


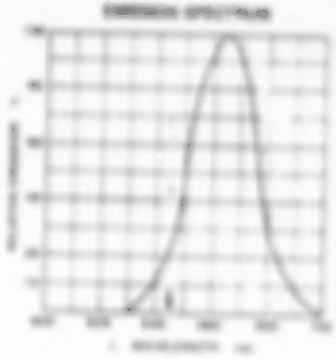


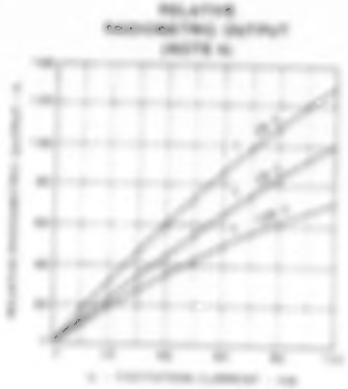




TYPICAL CHARACTERISTIC CURVES (Cont'd)







NOTES:

1. $\Delta I_F(pf)$ and $\Delta I_F(c)$ are the percentage derating factors for all radiometric output characteristics referenced to their typical value at 25°C ambient and $I_F = 100$ mA.
2. $\Delta\lambda_P(pf)$ and $\Delta\lambda_P(c)$ are the derating factors for all wavelength characteristics referenced to their typical value at 25°C ambient and $I_F = 100$ mA.
3. Time for a 10% to 90% change in light intensity with a step change in current.
4. Normalized: LED intensity = 1.0 (more details = each) axis.
5. Projected source point on the baseplate. Tip front when LED internal source unit characteristics may be computed for $Z = 0$ in.

$$R = \frac{Z \tan \theta_{1/2}}{\sin \theta} + \frac{\text{Tip}}{2 \cos \theta_{1/2}} \quad \text{Tip} = \text{Tip Spot}$$

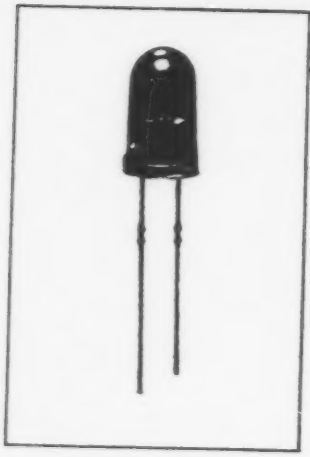
6. Irradiance (E_e) normalized to 1 mw/cm² @ $Z = 1$ cm

STANLEY
STANLEY ELECTRIC CO., LTD.

LIGHT EMITTING DIODES

T-1¾
(Ø5)

ESBR/SBR5501, 5531
SAR/SPR5531
ESBG5501 ESBG/SBG5531
SPG5531
ESPY5501 ESPY/SPY5531
ESAY5501 ESAY/SAY5531
ESAA5501 ESAA/SAA5531



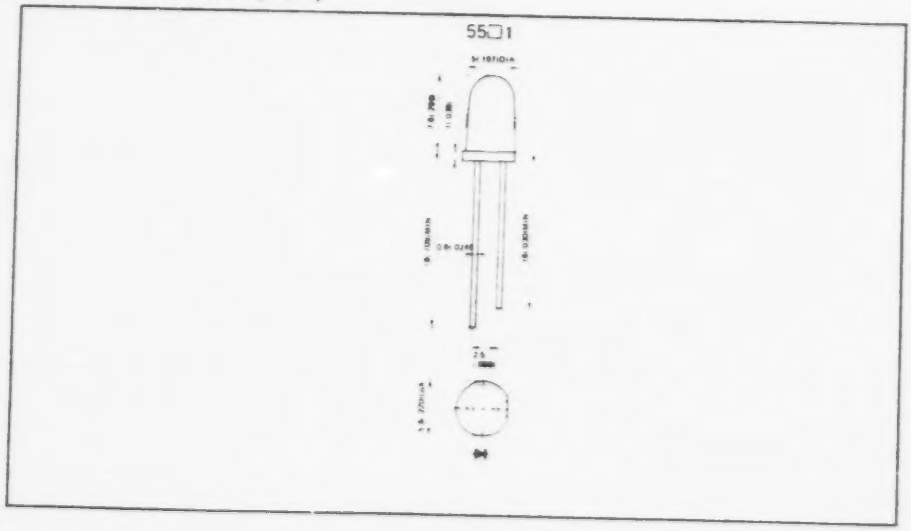
FEATURES

* 4 COLORS OF RED, GREEN, YELLOW AND AMBER
* 5MM DIA EPOXY PACKAGE
* WIDE AND NARROW VIEWING ANGLES AVAILABLE
* LOW CURRENT
* HIGH RELIABILITY

DESCRIPTION

ESBR, ESBG, ESPY, ESAY and ESAA stand for Super Bright Light Emitting Diode using GaAlAs, Gap and or GaAsP/Gap. Each LED is encapsulated in epoxy package with 5mm DIA and available in two types according to the package resin; one having wide viewing angle with diffusive agent and another with narrow viewing angle by which high brightness is obtained in axis direction in colored clear or transparent color.
SAR, SPR, SPG, SAY and SAA are the types using chip materials of GaAsP, GaP, GaAsP/GaP and two type can be selected likewise.

Package Dimensions—Unit in mm (inch)



Absolute Maximum Ratings at Ta = 25°C

Characteristics	Symbol	RED			GREEN		YELLOW		AMBER	Units
		ESBR5501 SBR5501			ESBG5501		ESPY5501	ESAY5501	ESAA5501	
		ESBR5531 SBR5531	SAR5531	SPR5531	ESBG5531 SBG5531	SPG5531	ESPY5531 SPY5531	ESAY5531 SAY5531	ESAA5531 SAA5531	
Power Dissipation	Pd	100	100	75	125	125	125	125	125	mW
Forward Current	IF	50	50	30	50	50	50	50	50	mA
Peak Forward Current	IFM	300	300	100	100	100	100	100	100	mA
Reverse Voltage	VR	4								V
Operating Temperature	Topr	-30 to +85								°C
Storage Temperature	Tstg	-30 to +100								°C
Lead Soldering Temperature		260°C for 5 seconds (3.0mm from body)								

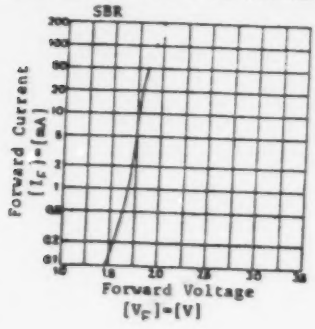
Electro-Optical Characteristics at Ta = 25°C

Test condition: IF=20mA (Only for SPR type IF=10mA)

Characteristics	Symbol	RED									GREEN						YELLOW						AMBER			Units
		ESBR5501 SBR5501									ESBG5501						ESPY5501			ESAY5501			ESAA5501			
		ESBR5531 SBR5531			SAR5531			SPR5531			ESBG5531 SBG5531			SPG5531			ESPY5531 SPY5531			ESAY5531 SAY5531			ESAA5531 SAA5531			
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Luminous Intensity	IV	80	160								50	80					80	160		60	90		60	90		mcd
		40	80																							
		20	30		1.5	3		3	6		8	12		12	24		30	45		16	24		16	24		
		8	20								5	8					15	30		8	16		8	16		
Peak Wave Length	λp		660			650			700			555			565			570			580			605		nm
Spectral Line Half Width	Δλ		30			30			100			30			30			30			30			30		nm
Capacitance V=0, f=1MHz	Co		50			40			70			50			50			40			40			50		pF
Forward Voltage	VF		1.7	2.0		1.7	2.0		2.1	2.5		2.1	2.5		2.1	2.5		2.1	2.5		2.2	2.5		2.2	2.5	V
Reverse Current VR=4V	IR			100			100			100			100			100			100			100			100	μA

Forward Current vs Forward Voltage

SBR



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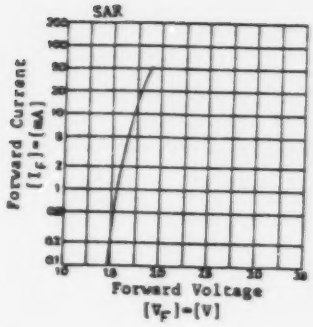

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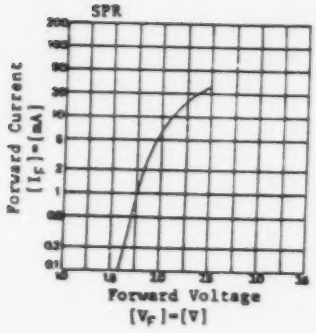
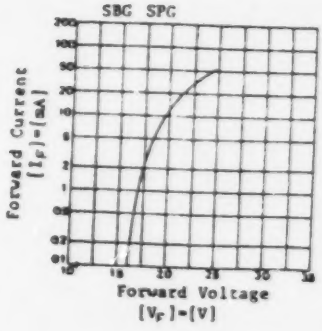


SBG SPG



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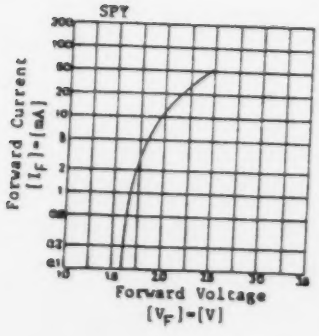
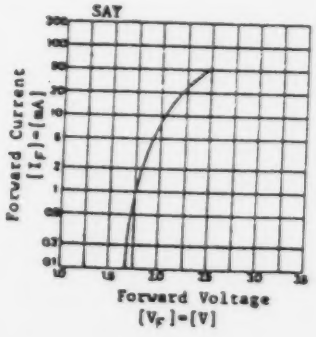


SAY



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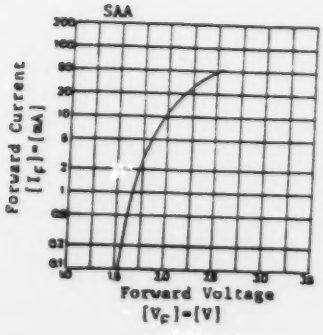
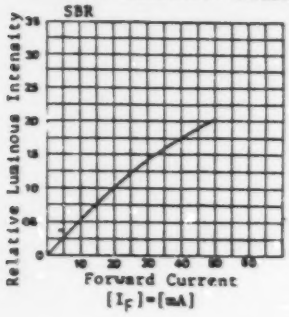


Relative Luminous Intensity vs Forward Current

SBR



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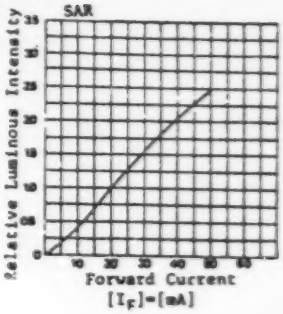

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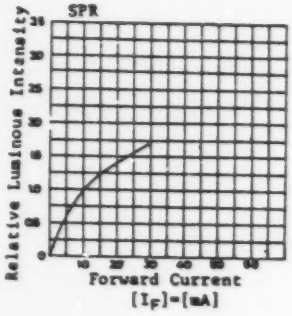

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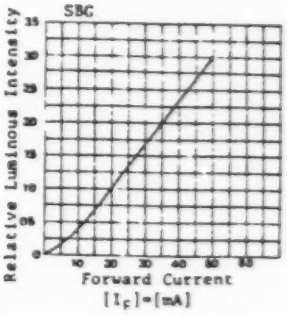
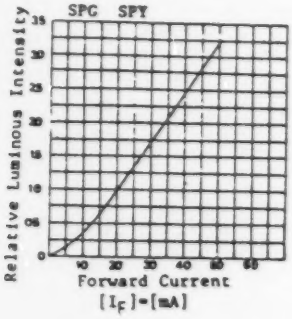


SPG SPY



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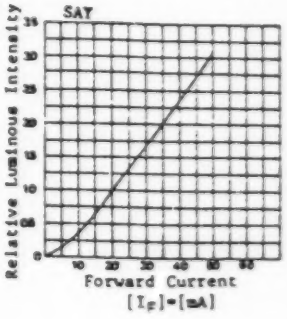

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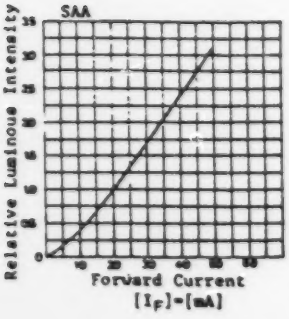
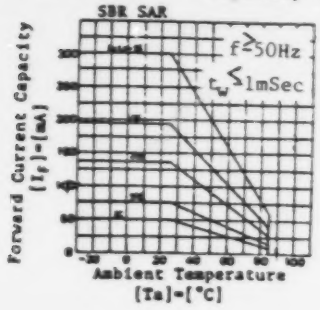
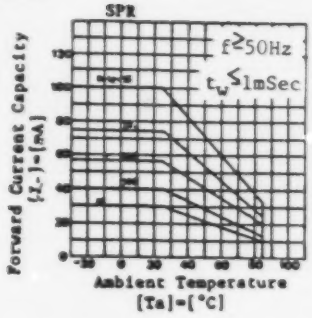
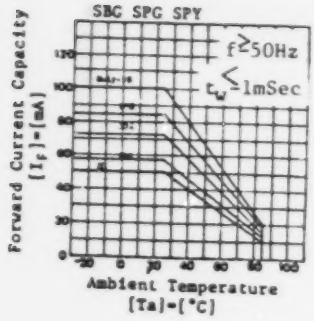
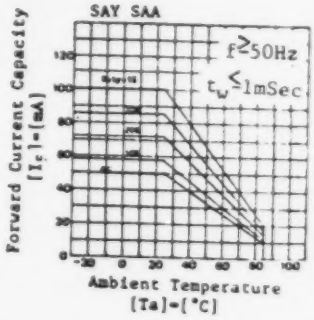


Forward Current Capacity vs Ambient Temperature

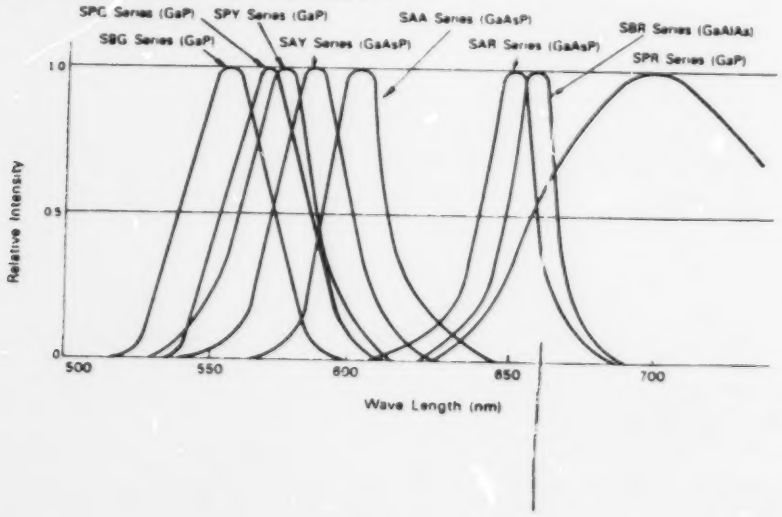




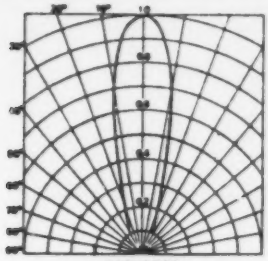




Relative Intensity vs Wave Length



Spatial Distribution



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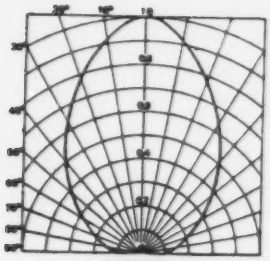
SBR5501



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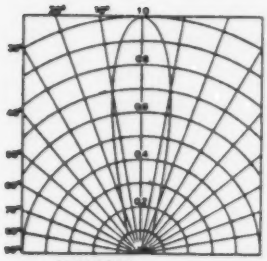
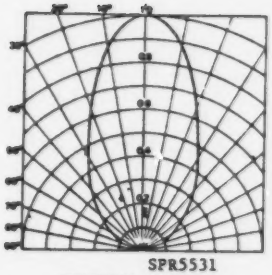


ESBG5501,
ESPY5501,SPY5501



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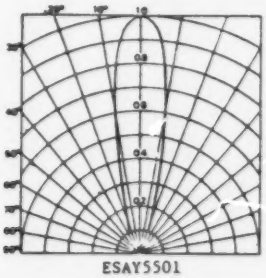
SPG5531
ESPY5531,SPY5531



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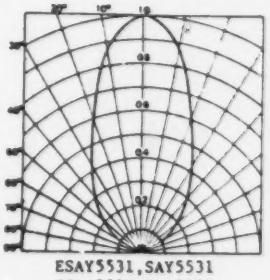
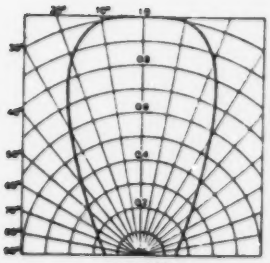


ESAY5531,SAY5531
ESAA5531,SAA5531



SAR5531

APPENDIX C

LED and Photometric Fundamentals
Tektronix Photometer Specifications
Soligor Photometer Specifications

Light Emitting Diodes, LED's, have come into widespread use on the electronics scene. This application note is intended to aid the designer in selecting a particular device from the many LED's offered today. The more important parameters as well as some little-known pitfalls are discussed.

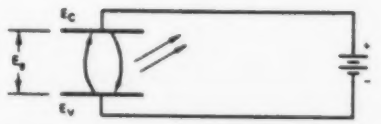
THEORY

Although light emission from a semiconductor junction had long been speculated, the first commercial devices did not become available until about 1963. This light emission phenomenon can be explained in terms of Semiconductor Energy-Band Theory. An external voltage applied to forward-bias a PN junction excites the majority carriers (electrons), causing them to move from the N-side Conduction Band to the P-side Valence Band. In making this transition the electrons cross the Energy Gap, E_g, that separates the two Bands, and so have to give up energy in the form of heat (phonons) and light (photons).

Each semiconductor material type has an E_g characteristic, and the wavelength (λ) of emitted light depends upon the magnitude of E_g, (see Figure 1). For example, Gallium Arsenide material, GaAs, has an E_g = 1.35 eV and a λ_{peak} = 9000 Å. The wavelength (i.e., color) emitted by some other materials made from Gallium compounds are listed in Table 1.

Material	Wavelength	Color
GaAs:Zn	9000A	infrared
$GaAsP_{.4}$	6600A	red
$GaAsP_{.5}$	6100A	amber
$GaAsP_{.85}$:N	5900A	yellow
GaP:N	5600A	green

Table 1. Some Wavelengths and Colors Emitted by Gallium Compounds



$$\text{Wavelength of Emission } (\lambda_{peak}) = \frac{12380}{E_g} \text{ (in Angstrom units)}$$

[Equation 1]

Fig. 1. Relationship Between Band-Gap Energy and Wavelength

Pulsed Operation. Significantly higher peak LED light output can be obtained from ampere-level drive current pulses (of narrow width and at low duty cycle) than from steady-state driving. For example, total radiated power (expressed in milliwatts) from a ME7021, infrared-emitting LED, operated steady-state (typically with I_F = 100 mA) is 2 mW. But this output increases to 50 mW when driven by a 6 amp, one microsecond-wide pulse at 0.1% Duty Cycle. It should be pointed out that this factor of 25 increase comes at the expense of a somewhat lower internal (quantum) efficiency.

Besides the increase in average power just described, pulsed operation of visible-emitting LED's also gives rise to a human perception phenomenon commonly known as Light Enhancement. This phenomenon is due in part to the eye's retention of high brightness levels (such as those produced by camera flash bulbs). A numerical Light Enhancement Factor (always greater than 1) can be defined by the following ratio:

$$\text{Light Enhancement Factor} = \frac{I_{DC \text{ (steady-state operation) to produce Brightness "B"}}}{I_{average \text{ (pulsed operation) to produce Brightness "B"}}}$$

[Equation 6]

This Light Enhancement phenomenon is available only from GaAsP because this LED material will not saturate under high-current conditions.

When the human eye is the detector of visible energy, lower average power is consumed by pulsed operation than by steady-state operation. This advantage of pulsed operation is especially important for battery-powered applications and for applications in which large LED arrays are being driven.

OPTICAL CONSIDERATIONS

Lens Effects. Lenses of the earliest LED's were designed to pass maximum light in the forward direction, i.e., perpendicular to the mounting surface, (see Figure 10). Later LED's produced more light and their lenses were designed to spread light over a wider area, thus permitting broader observer viewing angles. Still later, as higher light output LED's became available, a variety of red-colored, epoxy lenses came into use. These lenses act to diffuse light into a broader apparent emitting area. LED lenses that produce a broad, evenly-diffused light

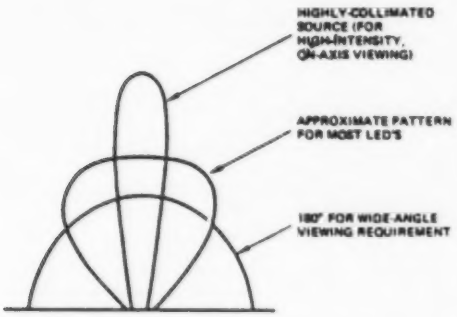

HIGHLY-COLLIMATED SOURCE (FOR HIGH-INTENSITY, ON-AXIS VIEWING)
APPROXIMATE PATTERN FOR MOST LED'S
180° FOR WIDE-ANGLE VIEWING REQUIREMENT

Fig. 10. Different Lens Effects (Used on the Same LED)

are generally assumed to be more pleasing to the eye than lenses that produce a highly-intense point of light. Figure 11 illustrates the effects of adding varying amounts of red diffusants to the epoxy lens material.

(a) Clear Lens (Point Source) (b) Partially Diffused (c) Fully Flooded (Area Source)

Fig. 11. Epoxy Lenses With Varying Amounts of Diffusants

Light Measurement. The manner by which the human eye "sees" is highly subjective and is affected by various factors such as "nature" of the light source (i.e., "point" or "area" source), viewing distance, color, and the observer's visual acuity. For example, it has been found that a "standard" observer with 20/20 vision can discern objects having dimensions that transcribe angles as small as two minutes. To such an observer a source having a 0.16-inch diameter and positioned farther away than 22 feet seems more "point" than "area" in nature.

Two photometric parameters which designers find useful for evaluating LED light output are Luminous Intensity, I, and Luminance (Brightness), B, (see Table 2). While an infinitely-small light source exists in theory only, the following expression can provide a means for determining the distance at which the eye loses its ability to discern an "area" and begins to see a "point."

$$\text{THRESHOLD DISTANCE} = \frac{\text{Diameter of Light Source}}{\text{TAN } 0^\circ 2'}$$

(At which sources "lose" their area) [Equation 7]

From this determination the designer can decide whether to use the I or B parameter for his evaluation of LED light output. The "diameter of the light source" in Equation 7 is the apparent emitting area of the LED. For a "clear" lens LED, (Figure 11a), multiply diode emitting area by the lens magnifying factor. (Unless stated otherwise, most clear lenses magnify by about 2X.) For a "flooded" lens LED, (Figure 11c), use the outside package diameter. For a partially-diffused lens LED, (Figure 11b), a good rule of thumb is one-half the outside package diameter.

Nature of Source	Photometric Parameter	Symbol	Units	Measurement of
Point	Luminous Intensity	I	candela	Luminous Flux/steradian
Area	Luminance (Brightness)	B	foot-Lambert	$\frac{\text{Luminous Flux/steradian}}{(\pi)(\text{Area of source in ft}^2)}$
			stilb	$\frac{\text{Luminous Flux/steradian}}{\text{Area of source in cm}^2}$

Table 2. I and B Photometric Parameters

Contrast Ratio. The degree by which an observer distinguishes an object or source is a function both of time spent looking and of Contrast Ratio. Contrast Ratio is defined as "the difference in Luminance between an object and its background," or

$$\text{CONTRAST RATIO} = \frac{L_s - L_b}{L_b}$$

where "L_s" is a Source Luminance and "L_b" is Background Luminance

[Equation 8]

After an observer has focused on an object for longer than about one second, the time factor becomes negligible and Contrast Ratio remains as the important factor.

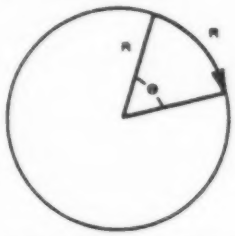
Human Factors Studies have shown that a Contrast Ratio of 10 is the minimum design value.

REVIEW OF GEOMETRIC PRINCIPLES

Any short discourse on the subject of photometry requires a brief review of geometric principles utilized.

RADIAN

In plane geometry the angle whose arc is equal to the radius generating it is called a radian. Therefore, if $C = 2\pi R$ (Circumference of a circle) $2\pi R = 360^\circ$. Radian = $180^\circ/\pi = 57.27^\circ$ (approx.)

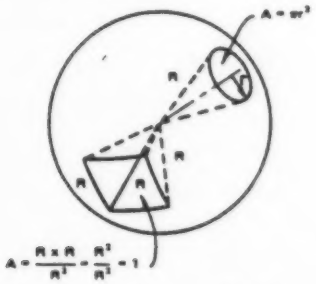


TWO DIMENSIONAL FIGURE

FIGURE 1

STERADIAN

In solid geometry one steradian is the solid angle subtended at the center of a sphere by a portion of the surface area equal to the square of the radius of the sphere. Therefore, if $AREA/R^2 = 1 = 1$ steradian and the area on the surface of a sphere equals $4\pi R^2$, then $4\pi R^2/R^2$ or 4π steradians of solid angle ω about the center of a sphere. The steradian is usually abbreviated as STER.



THREE DIMENSIONAL FIGURE

FIGURE 2

Other abbreviations of immediate concern are:

- Ae = Area of emitting (or reflecting) surface.
- Ap = Apparent area of an emitting source whose image is projected in space and viewed at some angle, Θ.
- Ad = Detection area. Whether a physical target or merely a defined spatial area, it is the area of interest.

PHOTOMETRIC TERMINOLOGY

FLUX (Symbol F)

Any radiation, whether visible or otherwise, can be expressed by a number of FLUX LINES about the source, the number being proportional to the intensity of that source. This LUMINOUS flux is expressed in LUMENS for visible radiation.

LUMINOUS EMITTANCE (Symbol L)

A source measurement parameter. It is defined as the ratio of the luminous flux emitted from a source to the area of that source, or $L = F/Ae$. Typically expressed in units of:

lumens/cm^2 or one PHOT,
lumens/m^2 or one LUX (or one METER CANDLE),
lumens/ft^2 or one FOOT CANDLE.
The foot candle is the more common term used in this country.

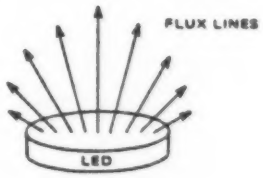


FIGURE 3

ILLUMINANCE (Symbol E)

This is a target or detector area measurement parameter. It is the ratio of flux lines incident on a surface to the area of that surface or E = L/Ad. Typical measurement units are the same for LUMINOUS EMITTANCE (above) i.e. lumen/cm^2 = one phot, lumen/m^2 = one lux, and lumen/ft^2 = one ft. candle.

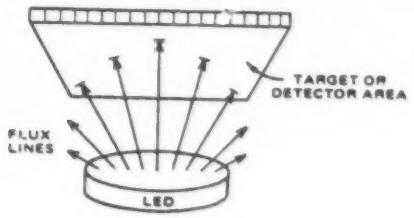


FIGURE 4

LUMINOUS INTENSITY (Symbol I)

A spatial flux density concept. It is the ratio of luminous flux of a source to the solid angle subtended by the detected area and that source. The LUMINOUS INTENSITY of a source assumes that source to be point rather than an area dimension. The LUMINOUS INTENSITY (or CANDLE POWER) of a source is measured in LUMENS/STERADIAN which is equal to one CANDELA (or loosely, one CANDLE).

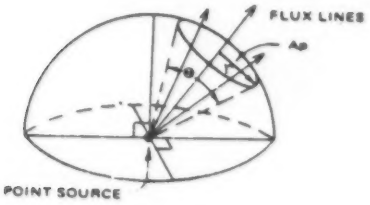


FIGURE 5

LUMINANCE (Symbol B)

Sometimes called photometric brightness (although the term brightness should not be used alone as it encompasses other physiological factors such as color, sparkle, texture, etc.) it is applied to sources of appreciable area size. Mathematically, if the area of an emitter (circular for example) has a diameter or diagonal dimension greater than 0.1 the distance to the detector, it can be considered as an area source. If less than this 10% figure, the source can be treated as point in nature. This one to ten ratio of source diameter to distance is offered as it MATHEMATICALLY very closely approximates results obtained when comparing an area source to its point equivalent. LUMINANCE presents itself as an extremely useful parameter as it applies a figure of merit to:

1. Apparent or protected area of the source (Ap).
2. Amount of luminous flux contained within the projected area of the source (Ap).
3. Solid angle the projected area generates with respect to the center of the source.

NOTE: The projected area Ap varies directly as the cosine of Θ i.e. max. at 0° or normal to the surface and minimum at 90°

$$Ap = Ae \cos \Theta$$

LUMINANCE is defined as the ratio of LUMINOUS INTENSITY to the projected area of the source Ap.

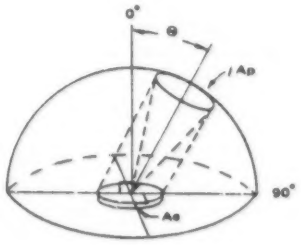


FIGURE 6

$$\frac{\text{LUMINOUS INTENSITY}}{Ap} = \frac{\frac{\text{LUMENS}}{\text{STERADIAN}}}{Ae \cos \Theta} = \frac{\text{CANDELAS}}{\text{(Sq. Unit)}}$$

And depending on the units used for area:

1 CANDELA/cm^2 = 1 STILB
1 CANDELA/m^2 = 1 NIT
1 CANDELA/in^2 =) no designator available.
1 CANDELA/ft^2 =)

Also:

1/π candela/cm^2 = LAMBERT
1/π candela/m^2 = APOSTILB (or BLONDEL)
1/π candela/in^2 = no designator available
1/π candela/ft^2 = FOOT LAMBERT

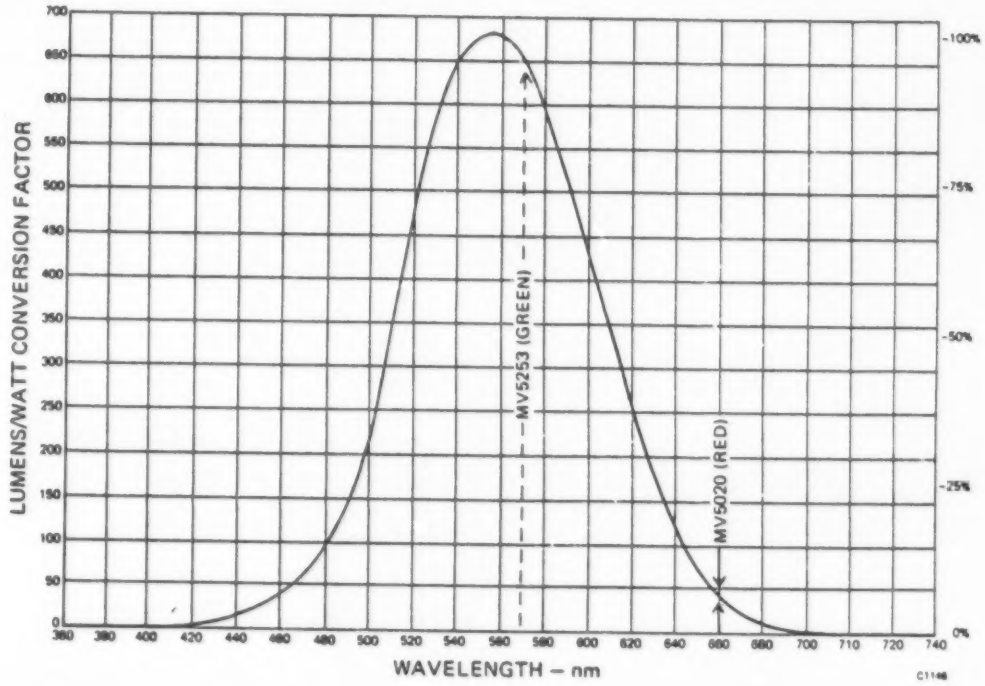
CIE CURVE

Following is the standard observer curve or "standard eyeball" established by the Commission Internationale de l'Eclair (commonly called the CIE curve). Whereas one watt of radiated energy at any frequency corresponds to one watt of radiated energy at any other frequency, this relationship fails to hold true for photometric measurement. The CIE curve is essential therefore, not only in determining the eye's efficiency at any particular wavelength, but also the corresponding lumens per watt conversion of that particular wavelength.

For example, the MV5020 which emits 180 μW of radiant energy at 6600Å (typical) or 41.4 lumens per watt has

$$180 \times 10^{-6} \text{ watts} \times \frac{41.4 \text{ lumens}}{\text{watt}} = 7.45 \text{ mLumens}$$

of flux emitted from it.



Similarly, a green emitter such as the MV5253 operating at an identical input power as the red will emit 10 μwatts of radiant energy or

$$10 \times 10^{-6} \text{ watts} \times \frac{649 \text{ lumens}}{\text{watt}} = 6.49 \text{ mLumens}$$

of flux emitted from it. In short although there exists at least an order of magnitude difference in radiant power the eyes' compensating effect "magnifies" the green to appear equally bright.

LUMINOUS INTENSITY versus LUMINANCE

The successful application of either measurement parameter as a yardstick to duplicate mathematically the visual stimulation experienced by an observer is a controversy which will probably rage for some time. As the entire electromagnetic spectrum is bounded only by the capabilities of a detector to discern it, so for within the visual spectrum the eye is the limiting factor. SUBJECTIVELY speaking, the eye can discern finer increments of arc (computed from target to eye) than a 1 to 10 relationship, or approximately 5° 43 min. In fact, it can be shown that for view angles of much less than 2 minutes, the eye translates the source into a point and thus the photometric measurement of LUMINOUS INTENSITY (in candelas) most directly correlates with subjective brightness. For view angles of much greater than approximately 2 minutes, the eye sees the source as an area source, and thus the photometric measurement of LUMINANCE most directly correlates with subjective brightness. A two minute view angle computes to a 1/1666 ratio of source diameter to distance ratio. For the MV5025 this computes to approximately 22 feet (1666 x .16" diameter, approximately 22 feet) well within the expected normal viewing distance of an observer.

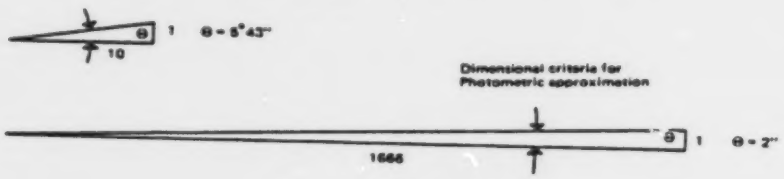


FIGURE 7

Considering that the usage of the discrete MV5025 LED is as an indicator and as such is utilized arms length or approximately 30" away, it can be seen that the LUMINANCE parameter and its basic unit, the FOOT LAMBERT, most closely correlates with subjective brightness.

Below are the products, their respective chip dimension, either diameter or diagonal, apparent size due to optical magnification and luminance/luminous intensity crossover distance. It should be stressed that this distance is not finite but represents a gradual threshold distance at which either parameter might be definitive.

Product	Active Chip Area	Optical Lens Factor	Apparent Size	Crossover Distance Feet
MV10B	.015"	x1.9	.028"	3.96
MV50	.017" diag.	x1.75	.030"	3.0
MV5020	.017" diag.	x1.5	.025"	2.5
MV5025	(.160")*	(x15.2)	.160"	22.2

*Entire lens is considered the apparent emitting area.

RADIOMETRY

While photometric units are concerned with only the visible spectrum of wavelength, all frequencies of emission, including the visible are expressable in RADIOMETRIC terms. Radiometric terms and their photometric equivalents are as follows:

RADIOMETRIC	PHOTOMETRIC
Radiant flux (Symbol P) expressed in watts	Luminous flux (F) expressed in lumens
Irradiance (Symbol H) expressed in watts/sq. unit	Illuminance (E) expressed in lumens/sq. unit
Radiant Emittance (Symbol W) expressed in watts/sq. unit	Luminous Emittance (L) expressed in lumens/sq. unit
Radiant Intensity (Symbol J) expressed in watts/steradian	Luminous Intensity (Symbol I) expressed in lumens/steradian
Radiance (Symbol N) expressed in watts/ster/sq. unit	Luminance (B) expressed in lumens/ster/sq. unit

	Parameter and Symbol		Definition	Units	Abbrev.
RADIOMETRIC	Radiant Energy	Q_e		erg joule calorie kilowatt-hour	 J cal kWh
	Radiant Flux	P	$P = \frac{dQ_e}{dt}$	erg per second watt	$erg\ s^{-1}$ W
	Radiant Emittance (see Note 2)	W	$W = \frac{dP}{dA}$	watt per sq. cm, watt per sq. m, etc.	$W\ cm^{-2}$ $W\ m^{-2}$
	Irradiance	H	$H = \frac{dP}{dA}$	watt per sq. cm, watt per sq. m, etc.	$W\ cm^{-2}$ $W\ m^{-2}$
	Radiant Intensity (see Note 1)	J	$J = \frac{dP}{d\omega}$	watt per steradian	$W\ sr^{-1}$
	Radiance (see Note 1)	N	$N = \frac{d^2P}{d\omega(dA \cos\Theta)}$ $N = \frac{dJ}{(dA \cos\Theta)}$	watt per steradian and sq. cm watt per steradian and sq. m	$W\ sr^{-1}\ cm^{-2}$ $W\ sr^{-1}\ m^{-2}$
PHOTOMETRIC	Luminous Efficacy	K	$K = \frac{F}{W}$	lumen per watt	$lm\ W^{-1}$
	Luminous Efficiency	V	$V = \frac{K}{K_{maximum}}$		
	Luminous Energy (quantity of light)	Q_v	$Q_v = \int_{380}^{760} K(\lambda) Q_e \lambda d\lambda$	lumen-hour lumen-second (talbot)	lm h lm s
	Luminous Flux	F	$F = \frac{dQ_v}{dt}$	lumen	lm
	Luminous Emittance (see Note 2)	L	$L = \frac{dF}{dA}$	lumen per sq. ft	$lm\ ft^{-2}$
	Illumination (illuminance)	E	$E = \frac{dF}{dA}$	footcandle (lumen per sq. ft.) lux (lumen per sq. m) phot (lumen per sq. cm)	fc lx ph
	Luminous Intensity (candlepower)	I	$I = \frac{dF}{d\omega}$	candela (lumen per steradian)	cd
	Luminance (brightness)	B	$B = \frac{d^2F}{d\omega(dA \cos\Theta)}$ $B = \frac{dI}{(dA \cos\Theta)}$	candela per unit area stilb (candela per sq. cm) nit (candela per sq. m) foot-Lambert (cd per πft^2) apostilb (cd per πm^2) Lambert (cd per πcm^2)	$cd\ in^{-2}$, etc. sb nt ft-L asb L

NOTES: 1. ω is a solid angle through which flux from point source is radiated

Θ is angle between line of sight and normal to surface considered

λ is wavelength

2. W and L refer to "emitted from" and H and E refer to "incident on"

Why LEDs Instead Of Incandescents?

For many years incandescent lamps have been used successfully as panel lamps in electronic systems. However, great care had to be given to replacement procedures and voltage levels. They had to be easy to replace, because they often failed. They also required fairly high voltage levels to get satisfactory light output. When LEDs came into being as practical devices, they were touted as being the answer to all problems. They lived "forever" and they could run off common low voltages such as +5 V-dc.

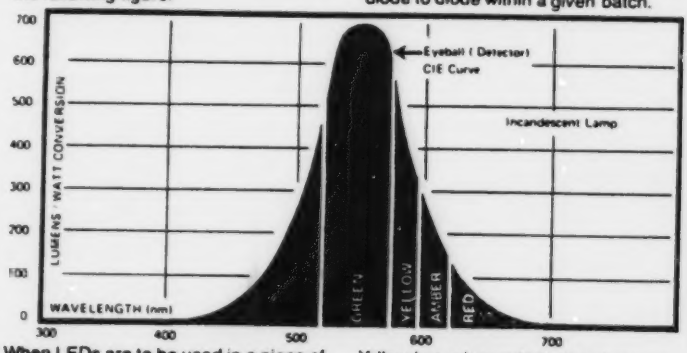
But ... like most panaceas, they were flawed. For some time, the light output was too low for many applications. And, you could get them in any color—as long as it was red. As the materials and the packaging technology moved along, LEDs became a real threat to incandescents. The super-bright materials came out, and the colors expanded to include amber, yellow and green, as well as red. LEDs suddenly appeared in packages that were interchangeable with incandescents. You could now pull out your old, tired incandescents, and replace them with LEDs that were comparable in performance and required no changes in any of the driving circuitry. Or ... you could design for LED usage in the first place, and eliminate the drawbacks of incandescent drive requirements.

LEDs are current devices, in contrast to incandescents, which are power devices. Whereas the light output of incandescents is proportional to the input power, the light output of LEDs is dependent only on the input current. More current means more brightness. Therefore, low voltage computer-type power supplies are ideal for driving LEDs.

Response time is another important advantage of LEDs over incandescents. LEDs turn on and off about 1,000,000 times faster than incandescents. Typical turn-on time is 10 ns, incandescents take several milliseconds.

Viewing The Spectrum

Brightness of light-emitting devices, whether they be diodes or incandescent filaments, must be viewed in relation to the optical response of the human eye. For example, a green light will appear to be brighter than a red light of the same optical output power. This is due to the fact that green is at the peak of the eye's response curve and red is down on a skirt of the curve. The relative positions in the spectrum of incandescent lamps, red, yellow, amber and green LEDs, and the human eye response can be seen in the following figure.



When LEDs are to be used in a piece of equipment, human judgement must be used in the early design stages. And ... more than one viewer should be used, due to the subjective nature of the design decision. Responses will vary from person to person and time to time. They may also vary with ambient light conditions. Factors that complicate the design decision in the selection of LEDs for a particular application, include the variations in color perception from one human being to another, as well as the fact that the human eye barely notices amplitude variations in LED output as large as a factor of two. Most designs assume that the human eye follows the "Standard Eyeball" or "CIE Curve" that is shown in the preceding illustration. This industry standard was established by the Commission Internationale de l'Eclair. Beware ... if you design with only that standard in mind, and do not include the subjective judgement of several human observers, you may select the wrong LED for your application.

What Do Color Names Mean?

Is it sufficient to say that an LED is green or yellow or red? A first time user of LEDs might stop at the data sheet statement of the color. But ... a more sophisticated user will want to know the variation in the wavelength of the LEDs. For example, a green LED from one manufacturer might appear close to emerald green and vary from emerald green to a slightly yellowish green, from diode to diode. And ... a green LED from another manufacturer might be more yellow than green. In one case you might like the color better, but in the other case, the color might be more consistent from diode to diode within a given batch.

Yellow is a prime culprit when it comes to specsmanship. What is yellow to one manufacturer may be amber to another and orange to a third. Don't accept color names at face value. Give the LEDs a subjective, as well as an objective check. And ... insist on color consistency throughout your order.

Why Do Green, Yellow and Amber Vary?

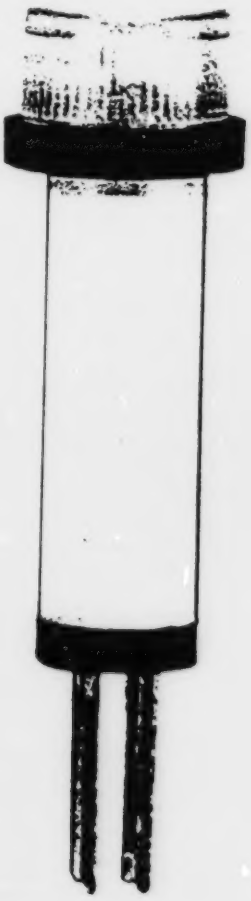
While you will often find wide variations in a batch of green, yellow or amber LEDs, red LEDs will seem to be quite consistent. Why is this? Looking back at the CIE Curve, you will notice that green, yellow and amber all have to deal with the steep skirt of the eye's response. On the other hand, red is down where the eye is less sensitive and the curve is flattening out. Yellow has the unfortunate honor of being the hardest to produce in a subjectively consistent way. Although the wavelength may not vary any more than that of a red LED, the human eye perceives that it does.

An additional factor of concern in the final application is that the LED can shift wavelength by as much as 10 nm due to changes in ambient temperature and drive current.

LED APPLICATIONS

Specification and use of light emitting diodes (LEDs) is a talent that is becoming more and more popular. But the marriage of electronics and optics is still not well understood by most designers. Evaluation of performance involves both subjective viewing and objective measurement.

And... specsmanship abounds in the electro-optics field. It is fed and nurtured by the lack of dependable applications assistance. The following guide will help you to lift the veil of misunderstanding, and to replace it with a well-focused lens.



An LED Mini-Glossary

The first step towards understanding any technology is a clear definition, in simple language, of the major terms used. This mini-glossary is far from complete. But ...it provides some necessary grounding in the basics.

Color

The mental representation of these portions of the electromagnetic spectrum that can be sensed by the human eye. LEDs tend to fall into the general color classifications of red, amber, yellow and green.

Foot-Lambert

The measurable unit of luminance is the foot-lambert. It is a measure of the total visible output of the LED per unit area.

Fresnel Lens

A large lens composed of many small lenses. These small lenses are often arranged in concentric circles. The net effect is a short focal length with high brightness.

GaAsP

Gallium Arsenide Phoshide is the basic material that red, yellow and amber LEDs are constructed from.

GaP

Gallium Phosphide is the basic material for making green LEDs.

Lifetime

LEDs do not normally fail catastrophically. They will die out slowly after living an unusually long time. Some technicians define the lifetime as: the length of time until the LED degrades to 50% of its original light output. However, in the real world, LEDs are usable far beyond their 50% points. It is not unusual to have LEDs last well in excess of 1,000,000 hours.

Luminance

Intensity per unit area of a light source is defined as luminance. The common unit is the foot-lambert.

Luminous Intensity

A measure of the total visible flux striking an optical detector, regardless of the size of the source. The common measure is the candela. The candela is one lumen per steradian of solid angle.

Microwatt

A measure of the total radiation from an LED, including both the visible and the invisible radiation as sensed by the human eye. This is a measure of total radiated output that is meaningless in most electro-optical applications.

Millicandela

This is the most common, and useful, measure of the total visible output of an LED. It is a measure of luminous intensity.

Monochromatic

Light output at a single wavelength is called monochromatic. LEDs are quite monochromatic. Even poorly made LEDs only emit light over a very narrow band.

Reflector

To get the maximum out of the LED along the viewing vector, various reflection media are often built into the LED package. These reflectors can substantially increase the light output in the forward direction.

Response Time

LEDs can emit light in response to an electrical stimulus much quicker than most other types of visible emitters. Typical turn-on time for an LED is 10 nanoseconds.

Spectrum

The array of visible colors arranged in order of their respective wavelengths is the spectrum. The visible spectrum is thought of as consisting of seven basic or core colors. They are: red, orange, yellow, green, blue, indigo and violet.

Translucent Lens

When a lens is frosted to effect light spreading, it is called translucent. Translucent lenses attenuate the light output of the LED somewhat, but they give a wider viewing angle, and a softer visual impression than do LEDs without translucent lenses.

Transparent Lens

When a lens is clear, or tinted the color of the monochromatic LED output, it is called transparent. This type of lens gives a very bright, but somewhat harsh, light output.

Viewing Angle

The solid angle over which the LED can be viewed with minimal light fall-off is called the viewing angle. Typical LEDs have viewing angles of about 30°. However, unique products—such as the LEDy Bug® from Data Display Products—are capable of viewing angles in excess of 180°.

Digital Photometer/Radiometer

J16 Photometer/Radiometer (Fig 1)

3½-Digit Light-Emitting Diode Readout

Portability and Versatility

Complete Probe Interchangeability without Recalibration

Available with Metric Readout

The J16 is a portable photometer/radiometer that is equally at home in the lab or in the field. It weighs 3.3 lb, measures 2.4 x 4.6 x 8 inches, and comes with a shoulder strap and rechargeable nickel-cadmium batteries. The J16 has excellent long-term calibration stability. It is environmentalized to operate from −15°C to +40°C and meet MIL specs for humidity.

Available for the J16 are eight quickly interchangeable, precalibrated silicon probes, an ac power supply, probe cable (for separate operation of the probes), and analog and bcd outputs.

All J16 Probes

Rugged, Stable Silicon Sensor and Glass Spectral-Correction Filter

Hold Switch to Store Reading

Calibration Accuracy of Reading 5% ± One Digit

No Fatigue or Saturation Effects

Excellent Calibration Stability

J6511 Illuminance Probe (Fig 2)

Accurate Photopic (Color) Correction

Accurate Cosine Correction (180° Field of View)

Measures 0.001 to 1999 Footcandles (0.01 to 19,999 Lux*)

Resolution 0.0001 Footcandles (0.001 Lux*)

5% Accuracy Even with Low-Pressure Sodium Lighting

25-Ft Cable Attached

Built-in Bubble Level

Use for OSHA Standards, Office Lighting, Highway Lighting, Automotive Lighting, Medical Lighting

J6523 1° Luminance Probe (Fig 3)

1° Acceptance Angle

Optical Sighting and Viewing System

Accurate Photopic (Color) Correction

Measures 0.1 to 19,990 Footlamberts (1 to 199,900 Nits*)

Resolution 0.01 Footlamberts (0.1 Nits*)

Measures a Spot as Small as 0.23 inches at 18-in Distance (0.035" with Commercially Available Standard Photographic Close-up Lenses)

Focus Range of 18 inches to Infinity

5% Accuracy Even with Low-Pressure Sodium Lighting

Use for Highway Lighting, Television Photographic Equipment, Cathode-Ray Tubes

*Metric version

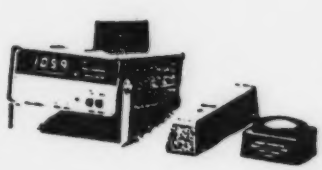


Fig 1

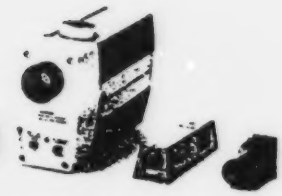


Fig 2 Fig 3 Fig 4 Fig 5

J6582 Irradiance Probe (Fig 4)

Flat Spectral Response within ± 7% from 450 to 950 nm

Measures 1 nW/cm² to 1.999 mW/cm² (0.01 to 19,900 mW/M²*)

Resolution 0.1 nW/cm² (0.001 mW/M²*)

1-cm² Sensor Allows Direct Reading of Laser Power in μW with Detector Underfilled by Beam

Acceptance Angle Approximately 120°

Use for Lasers, Environmental Research, Tv Monitor Color Temperature Adjustment, Ir LED's

J6583 8° Luminance Probe (Fig 4)

Accurate Photopic (Color) Correction

Measures 0.1 to 199,900 Footlamberts (1 to 1,999,000 Nits*)

Resolution 0.01 Footlamberts (0.1 Nits*)

Use for Television, Illumination, Photographic Equipment, Cathode-Ray Tubes

J6501 Illuminance Probe (Fig 4)

Same Characteristics as J6511 Except No Cosine Correction, Construction Similar to J6502. (When Using 014-0047-00 LED Adapter, the Ranges are the Same as Those for the J6505.)

Use for Green and Yellow LED's, Lamp Testing, and Other Point Light Sources

J6505 Red LED Probe (Fig 4 and 5)

Accurately Matches Photopic Curve from 600 to 710 nm

Measures 0.01 Millicandela to 199.9 Candelas at 3.8 Inches (Higher at Greater Distances)

Resolution 0.01 Millicandela

Includes Snap-on LED Adapter to Position LED and Exclude Room Light

Use for Red LED's, Red Automotive, and Aircraft Lights

J6512 Irradiance Probe (Similar to Fig 2)

Same Characteristics as J6502. Construction Similar to J6511

Use for Lasers, Medical, Environmental Research

J6504 Uncorrected Probe (Fig 4)

Spectral Response: Uv-Enhanced Silicon Curve (250 to 1200 nm)

Highest Sensitivity (No Filters Are Used to Modify Spectral Response)

Relative Reading Only

Use for Periodic Tests of Photoresist Exposure Equipment, Uv Light Sources

ORDERING INFORMATION

Photometer/Radiometer without Probes

Readout Units	Power Source	Voltage	Order Information†
US	Battery	115 V, 50-60 Hz battery charger	J16
US	Battery	230 V, 50-60 Hz battery charger	Opt 01
US	Ac	115 V, 50-400 Hz	Opt 03
US	Ac	230 V, 50-400 Hz	Opt 04

Analog and digital outputs available on special order

†For a J16 with metric readout, specify Option 02 in addition to above ordering information. No additional charge

Option 02 probes must be used with Option 02 J16

PROBES

J6511 Illuminance Probe

J6523 1° Luminance Probe

J6582 Irradiance Probe

J6583 8° Luminance Probe

J6501 Illuminance Probe

J6505 Red LED Probe

J6512 Irradiance Probe

J6504 Uncorrected Probe

For probes for metric J16, specify Option 02 at no additional charge

ACCESSORIES

42-in Probe Extension Cable for J6501, J6502, J6503, J6504, and J6505
Order 012-0410-02 (Longer on Special Order)

Light Occluder (for Color Tv Monitor Setup)
Order 016-0385-00

Filter Holder — Mounts 1-in Diameter Filters to J6501, J6502, J6503, J6504, and J6505
Order 016-0527-00

Filter Holder — Mounts 2-in Diameter Filters to J6512
Order 352-0300-00

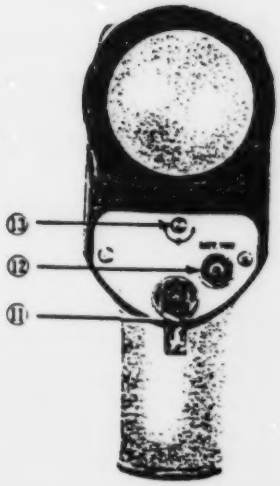
Tripod, Order 016-0253-00

Ac Power Supply, 115 V, 50-400 Hz
Order 119-0484-00

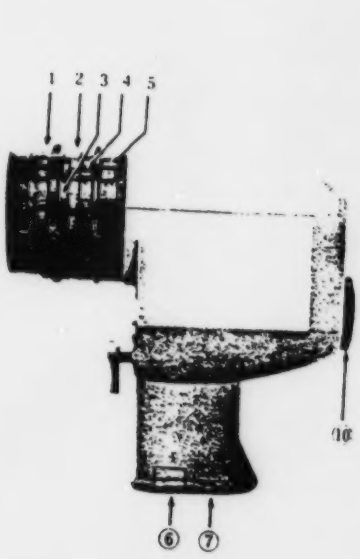
Ac Power Supply, 230 V, 50-400 Hz
Order 119-0484-01

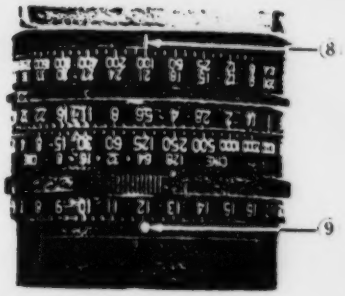
LED Adapter (included with J6505)
Order 014-0047-00

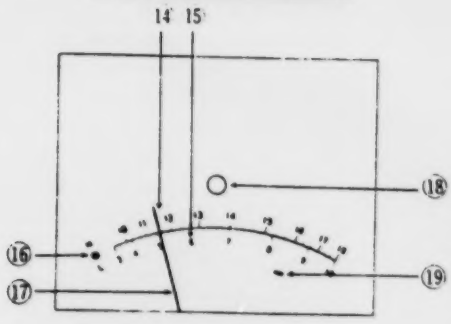
For a complete brochure and application notes on the J16, please return the reply card attached to the catalog or see your Tektronix field representative.



1 EV scale
2 Shutterspeed scale
3 Cine speed scale
4 Lens aperture
5 ASA and DIN scale
6 Battery compartment
7 Socket for wriststrap
8 Filmspeed mark
9 EV computor mark
10 Eyepiece, w/diopter adjustment
11 Operating switch (trigger)
12 Battery test button
13 Zero adjustment screw
14 "High" scale
15 "Low" scale
16 Zero mark
17 Indicator needle
18 Sensing spot
19 Battery test mark







What is the Soligor Spot/Sensor Meter ?

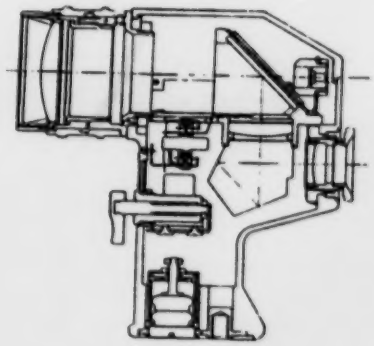
The Soligor Spot/Sensor is a professional exposure meter which measures an extremely narrow, 1°, angle of illumination. Conventional exposure meters read an area approximately equal to the area covered by the camera's normal lens. This results in an "average" reading. The result can be a poorly exposed photograph due to the exposure meter erroneously reading an unimportant area such as a very bright object or dark background. The Soligor Spot/Sensor Meter enables the photographer to measure the most important areas in the photograph to which he will key his exposure.

The Soligor Spot/Sensor Meter utilizes an ultra sensitive CdS cell so that extremely low light exposure measurements may be made.

As an example of a situation requiring the use of a spot meter, let us assume that you intend to photograph a person in bright sunlight on a beach or standing against a snow background. A standard meter would read the bright sands or snow and give you an inaccurate reading causing an under-exposure of your prime subject. With the Soligor Spot/Sensor Meter, however, you can read only the face of the person you are photographing and achieve a perfect exposure. In addition, if the subject is made up of very bright and dark areas you can read each individually and then average your exposure to achieve the best results.

How does the Soligor Spot/Sensor work ?

When the meter is pointed towards the subject, a beam of light enters the meter through the lens, and is reflected on to a mirror. In the center of the mirror is a small part which is half-coated, through which part of the light passes to activate the extremely sensitive Cadmium Sulphide (CdS) cell. This CdS cell activates the needle, visible in the viewfinder. The remaining light is reflected to the built-in penta-prism and is thus visible through the eyepiece. To determine the exact "spot" in the center of the field of view, a small circular mark is visible which should be pointed towards the subject.



Specifications

Angle of incidence: 1°

Angle of view, horizontal: 15°

Angle of view, vertical: 11°

Viewfinder: Diopter adjustment system

Pentaprism and condenser

EV-range: 3–18 (ASA 100)

low EV 3–10 High 10–18

ASA-range: 6–12,800 (DIN 9–42)

Shutter speeds: 1/4000 ~ 30 min.

Cine speeds: 8–16–32–64–128 fps

Lens opening: F:1~F:128

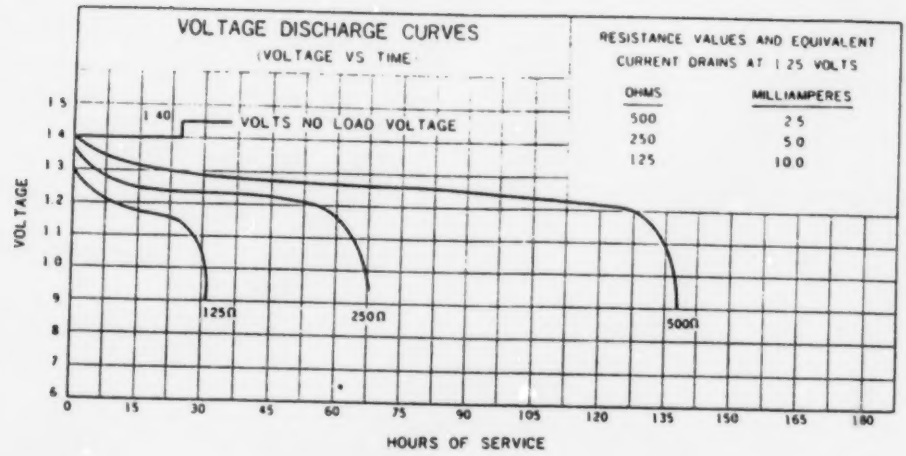
Batteries: 2 pcs. mercury 1.3V-1.40V (Mallory # RM 625 or equivalent)

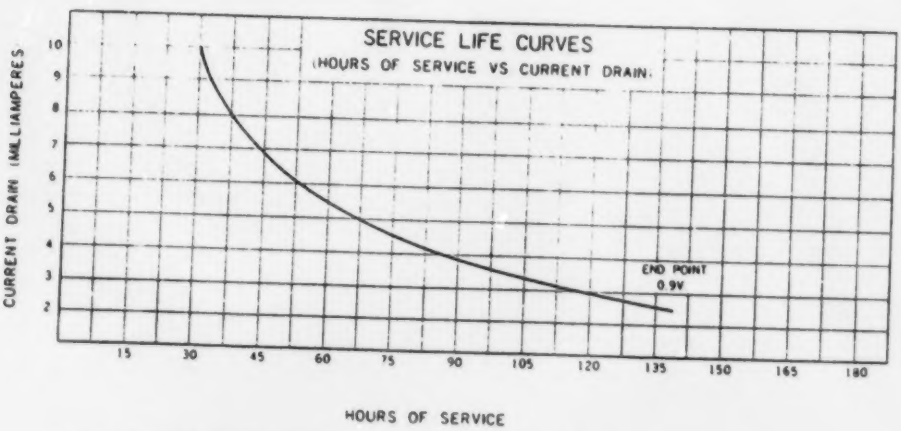
Measuring method: Direct reading system

Lens: 100mm f2.8. Fully coated.

Light Value Conversion Table

	Nits (nt)	Stilb (Sb)	Radlux (rlx)	Lamberts (L)	foot lamberts	
ASA 100 K=12.5	cd m²	cd cm²	lm m²	lm/cm²	(ft-L)	cd/ft²
EV 1	0.27986	0.000027986	0.87922	0.000087922	0.08168	0.026
2	0.55973	0.000055973	1.7584	0.00017584	0.16336	0.052
3	1.1195	0.00011195	3.5169	0.00035169	0.32672	0.104
4	2.2389	0.00022389	7.0338	0.00070338	0.65345	0.208
5	4.4978	0.00044978	14.068	0.0014068	1.3069	0.416
6	8.9557	0.00089557	28.135	0.0028135	2.6138	0.832
7	17.911	0.0017911	56.27	0.005627	5.2276	1.664
8	35.823	0.0035823	112.54	0.011254	10.455	3.328
9	71.645	0.0071645	225.08	0.022508	20.91	6.656
10	143.29	0.014329	450.16	0.045016	41.821	13.312
11	286.58	0.028658	900.32	0.090032	83.642	26.624
12	673.16	0.057316	1,800.64	0.180064	167.28	53.248
13	1,146.3	0.11463	3,601.3	0.36013	334.57	106.5
14	2,292.6	0.22926	7,202.6	0.72026	669.13	212.99
15	4,585.3	0.45853	14,405	0.4405	1,338.3	425.98
16	9,170.6	0.91706	28,810	2.881	2,676.5	851.97
17	18,341	1.8341	57,620	5.762	5,353.1	1,703.9
18	36,683	3.6682	115,241	11.5241	10,706	3,407.9
19	73,365	7.3365	230,482	23.0482	21,412	6,815.7
20	146,730	14.673	460,964	46.0964	42,825	13,631





NOTES: CURRENT DRAIN VALUES DETERMINED AT 1.25 VOLTS
INDICATED PERFORMANCE AT 70° F
ALL CURVES REPRESENT CONTINUOUS LOAD CONDITIONS

APPENDIX D

Software

CNLENS.FTN - Concept 3 Lens plotting
ARAYDI.FTN - Hexagonal close-packed diode plotting
ARAYPL.FTN - Hex close-packed Lens plotting
GRAFPLOT.FTN - Luminance vs Angle Data plotting

```
C CNLENS.FTN          27/2/84
      PROGRAM CNLENS
C THIS PROGRAM WILL PLOT THE PROFILE OF A COLLIMATING LENS
C GIVEN A NON IDEAL POINT SOURCE DIAMETER AND A DESIRED DISPERSION ANGLE .
C
      REAL N1,N2,PI
C
      CALL PLOTS(0,0,4)
C
      CALL PLOT(16.0,10.0,-3) ! SET ORIGIN AT VERTEX
C
      WRITE  (7,30)
30    FORMAT (/ '$ ENTER SOURCE DIAMETER ')
      READ   (7,10) DIAM
10    FORMAT (F5.4)
      WRITE  (7,40)
40    FORMAT (/ '$ ENTER DESIRSD DISPERSION ANGLE ')
      READ   (7,20) ANGLD
20    FORMAT (F5.2)
C
      PI   = 3.141592654
      ANGL = ANGLD * PI/180.          ! DEG TO RADIANS
      N1   = 1.0                      ! COEF OF REFRACTION FOR AIR
      N2   = 1.52                     ! LENS MATERIAL COEFF OF REFRACTION
      E    = N1/N2                    ! ECCENTRICITY OF LENS
C
      F1B = DIAM*COS(ANGL)/SIN(ANGL) ! 1/2 MAJOR AXIS
      EV  = 2. * F1B                  ! MAJOR AXIS LENGTH
      BG  = EV * E                    ! MINOR AXIS LENGTH
      BC  = BG / 2.                   ! 1/2 MINOR AXIS
C
C CALCULATE INVERSE SIN TO FIND ALPHA
      ALPHA  = .7                     ! FIRST GUESS
      ERLIM  = .000001
      ERR    = 0.0
100   ALPHA  = ALPHA + ERR
      ETEST  = SIN(ALPHA)
      ERR    = E - ETEST
      IF (ABS(ERR) .GT. ERLIM) GOTO 100
      ALPHAD = ALPHA * 180./PI        ! RADIANS TO DEGREES
C
      F1C  = F1B * COS(ALPHA)         ! DIST FROM A FOCUS TO CENTER
      F1F2 = 2. * F1C                 ! DIST BETWEEN FOCI
      F2V  = (EV - F1F2)/2.           ! DIST FROM FOCUS TO VERTEX
      F1V  = F1F2 + F2V               ! DIST FROM OTHER FOCUS TO VERTEX
      CV   = F1C + F2V                ! DIST FROM CENTER TO VERTEX
C
      WRITE  (7,200) EV,BG,F1F2
200   FORMAT(/' MAJOR AXIS=',F8.6,' MINOR AXIS=',F8.6,' F1F2=',F8.6)
C
      WRITE  (7,220) F1V,F1C,CV,ALPHAD
220   FORMAT(/' F1V=',F8.6,' F1C=',F8.6,' CV=',F8.6,' ALPHA=',F9.5)
C
      RMAJ = CV * 2.54                ! CM
      RMIN = BC * 2.54                ! CM
      XF1V = F1V * 2.54               ! CM
      ELPISE (XPAGE,YPAGE,RMAJ,RMIN,ANGLE,THD,THF,IPEN)
      CALL ELIPS (0.0,0.0,RMAJ,RMIN,0.0,0.0,360.0,3)
C
      XORIG = -1. * XF1V
      CALL PLOT(XORIG,0.0,-2)         ! DEF ORIGIN AT FOCUS
C
```

```
C DRAW RECT PART OF LENS PROFILE
      YNEG = -1. * RMIN
      XF1C = F1C * 2.54
      CALL PLOT(0.0,RMIN,2)
      CALL PLOT(XF1C,RMIN,2)
      CALL PLOT(XF1C,YNEG,2)
      CALL PLOT(0.0,YNEG,2)
      CALL PLOT(0.0,0.0,2)
C
      CALL PLOT(0.0,0.0,-3)          ! PURGE BUF
C
      CALL PLOTS(0,0,4)              ! REDEFINE ORIGIN
C
C SYMBOL (XPAGE,YPAGE,HEIGHT,TEXT,ANGLE,+NCHAR)
C NUMBER (XPAGE,YPAGE,HEIGHT,NUMBER,ANGLE,+NDEC)
      XPOS = 3.0
      YPOS = 24.0
      HITE = .36
      THETA= 0.0
      NCHAR= 10
      CALL SYMBOL(XPOS,YPOS,HITE,'CMLENS.FTN',THETA,NCHAR)
      YPOS = YPOS - .8
      NCHAR= 24
      CALL SYMBOL(XPOS,YPOS,HITE,'UNITS = INCHES & DEGREES',THETA,NCHAR)
C
      YPOS = YPOS - .8
      CALL SYMBOL(XPOS,YPOS,HITE,'DISPERSION ANGLE      =',THETA,NCHAR)
      NDEC = 5
      XPOSN= 12.4
      CALL NUMBER (XPOSN,YPOS,HITE,ANGLD,THETA,NDEC)
C
      YPOS = YPOS - .6
      CALL SYMBOL(XPOS,YPOS,HITE,'SOURCE DIAMETER       =',THETA,NCHAR)
      CALL NUMBER (XPOSN,YPOS,HITE,DIAM,THETA,NDEC)
C
      YPOS = YPOS - .6
      CALL SYMBOL(XPOS,YPOS,HITE,'N2                    =',THETA,NCHAR)
      CALL NUMBER (XPOSN,YPOS,HITE,N2,THETA,NDEC)
C
      YPOS = YPOS - .6
      CALL SYMBOL(XPOS,YPOS,HITE,'SOURCE TO VERTEX      =',THETA,NCHAR)
      CALL NUMBER (XPOSN,YPOS,HITE,F1V,THETA,NDEC)
C
      YPOS = YPOS - .6
      CALL SYMBOL(XPOS,YPOS,HITE,'F1F2                  =',THETA,NCHAR)
      CALL NUMBER (XPOSN,YPOS,HITE,F1F2,THETA,NDEC)
C
      YPOS = YPOS - .6
      CALL SYMBOL(XPOS,YPOS,HITE,'MAJOR AXIS            =',THETA,NCHAR)
      CALL NUMBER (XPOSN,YPOS,HITE,EV,THETA,NDEC)
C
      YPOS = YPOS - .6
      CALL SYMBOL(XPOS,YPOS,HITE,'MINOR AXIS            =',THETA,NCHAR)
      CALL NUMBER (XPOSN,YPOS,HITE,BG,THETA,NDEC)
C
      YPOS = YPOS - .6
      CALL SYMBOL(XPOS,YPOS,HITE,'LIGHT COLLECTION ANGLE =',THETA,NCHAR)
      XPOSN = XPOSN - .36
      ALPHAT = 2. * ALPHAD
      CALL NUMBER (XPOSN,YPOS,HITE,ALPHAT,THETA,NDEC)

      CALL PLOT(0.0,0.0,-3)          ! PURGE BUF

C
      END
```

```
C ARAYD1.FTN
C              20/2/84
C
      PROGRAM ARAYD1
C
      WRITE  (7,11)
11    FORMAT (/ '$ NUMBER OF DIODES PER SIDE = ')
      READ   (7,22) NDPS      ! NUMBER OF DIODES PER SIDE
22    FORMAT (I2)
      WRITE  (7,33)
33    FORMAT (/ '$ DIODE LENS DIAMETER IN INCHES = ')
      READ   (7,44) DIAM
44    FORMAT (F6.5)
C
      PI     = 3.14159246
      TM     = 1./6.                  ! TOTAL MULTIPLIER
      NDPL   = NDPS-1                 ! INT NUM OF DIODES PER LINE
      DO 55 I= 1,NDPL
      TM     = TM + FLOAT(I)
55    CONTINUE
      TNDD   = TM * 6. + .1           ! TOTAL NUMBER OF DIODES
C
      DRIL   = .25 * 2.54/2.          ! DIODE APURTURE RADIUS IN cm
      XSPOS  = 8.                     ! INITIAL X POSITION
      YPOS   = 18.                    ! INITIAL Y POSITION
      PPO    = 2.54*.1/2.             ! PUNCH POINT OFFSET IN cm
      DIAMM  = 2.54 * DIAM            ! DIAMETER IN cm
      R      = DIAMM/2.               ! RADIUS IN cm
C
      CALL PLOTS(0,0,4)               ! INIT PLOTTER
      CALL PLOT(1.0,1.0,-3)           ! DEFINE ORIGIN
C
      NROWS = 2*NDPS-1                        ! ROWS OF DIODES
      DO 99 LINE = 1,NROWS                    ! NUMBER OF ROWS TO PLOT
      IF (LINE .LE. NDPS) NDPL = NDPL + 1     ! INCREASING DIODES PER LINE
      IF (LINE .GT. NDPS) NDPL = NDPL - 1     ! DECREASING DIODES PER LINE
      IF (LINE .LE. NDPS) XSPOS=XSPOS-DIAMM/2. ! INCREASING DIODES PER LINE
      IF (LINE .GT. NDPS) XSPOS=XSPOS+DIAMM/2. ! DECREASING DIODES PER LINE
      XPOS = XSPOS
C
      DO 88 NOD = 1,NDPL                      ! PLOT CURRENT ROW OF DIODES
C     CALL CIRCLE(XPOS,YPOS,0.0,,DRIL,6)      !LENS MOUNTING PLATE HOLE SIZE
      CALL CIRCLE(XPOS,YPOS,0.0,,R,6)         ! LENS OUTLINE
      YPPP = YPOS + PPO                       ! PUNCH POINT OFFSET
      CALL PLOT(XPOS,YPPP,3)                  ! START OF PUNCH POINT
      YPPP = YPOS - PPO                       ! BOTTOM OF PUNCH POINT
      CALL PLOT(XPOS,YPPP,2)                  ! PEN DOWN
      XPPP = XPOS - PPO                       ! LEFT SIDE OF PUNCH POINT
      CALL PLOT(XPPP,YPOS,3)                  ! PEN UP
      XPPP = XPOS + PPO                       ! RIGHT SIDE OF PUNCH POINT
      CALL PLOT(XPPP,YPOS,2)                  ! PEN DOWN
      XPOS = XPOS + DIAMM
C     DO 80 IDLE  = 1,20000                   ! WAIT LOOP TO ALLOW PLOTTER
C80   CONTINUE                                ! TO EMPTY BUFFER
C
88    CONTINUE                                ! COLLUMN LOOP
      YPOS = YPOS - DIAMM * COS(PI/6.)
99    CONTINUE                                ! ROW LOOP
C
      CALL PLOT(0.0,0.0,-3)                   ! PURGE BUFFER
C
C SYMBOL (XPAGE,YPAGE,HEIGHT,TEXT,ANGLE,NCHAR)
```

```
C  PLOT TITLE AND DESCRIPTION
C
        CALL SYMBOL(TITLEX,FILEY,.24,FILNAM(1),0.0,NFCHAR)
        CALL SYMBOL(TITLEX,TITLEY,.3,TITLE(1),0.0,NTCHAR)
500     CALL SYMBOL(TITLEX,DSCPTY,.24,DSCPTN(1),0.0,NDCHAR)
        DSCPTY = DSCPTY - 0.5
C
C       Return pen to lower left-hand corner of plotting page
C
610     CALL PLOT(0.0,0.0,-3)   !PURGE BUFFER
C
        AXOMIT = .TRUE.
        GO TO 10
C
222     WRITE (TLUN,223)
223     FORMAT(/' LAST DATA POINT MUST BE "999999.999,0.0"')
        STOP
        END
```

```
C ARAYPL.FTN
C             28/2/84
C
      PROGRAM ARAYPL
C
      WRITE  (7,11)
11    FORMAT (/ '$ NUMBER OF DIODES PER SIDE = ')
      READ   (7,22) NDPS      ! NUMBER OF DIODES PER SIDE
22    FORMAT (I2)
      WRITE  (7,33)
33    FORMAT (/ '$ DIODE LENS DIAMETER IN INCHES = ')
      READ   (7,44) DIAM
44    FORMAT (F6.5)
C
      PI     = 3.14159246
      TM     = 1./6.                  ! TOTAL MULTIPLIER
      NDPL   = NDPS-1                 ! INT NUM OF DIODES PER LINE
      DO 55 I= 1,NDPL
      TM     = TM + FLOAT(I)
55    CONTINUE
      TNOD   = TM * 6. + .1           ! TOTAL NUMBER OF DIODES
C
      DRIL   = .25 * 2.54/2.          ! DIODE APURTURE RADIUS IN cm
      XSPOS  = 0.                     ! INITIAL X POSITION
      YPOS   = 10.                    ! INITIAL Y POSITION
      PPO    = 2.54*.1/2.             ! PUNCH POINT OFFSET IN cm
      DIAMM  = 2.54 * DIAM            ! DIAMETER IN cm
      R      = DIAMM/2.               ! RADIUS IN cm
C
      CALL PLOTS(0,0,4)                       ! INIT PLOTTER
      CALL PLOT(1.0,1.0,-3)                   ! DEFINE ORIGIN
C
      NROWS = 2*NDPS-1                        ! ROWS OF DIODES
      DO 99 LINE = 1,NROWS                    ! NUMBER OF ROWS TO PLOT
      IF (LINE .LE. NDPS) NDPL = NDPL + 1     ! INCREASING DIODES PER LINE
      IF (LINE .GT. NDPS) NDPL = NDPL - 1     ! DECREASING DIODES PER LINE
      IF (LINE .LE. NDPS) XSPOS=XSPOS-DIAMM/2. ! INCREASING DIODES PER LINE
      IF (LINE .GT. NDPS) XSPOS=XSPOS+DIAMM/2. ! DECREASING DIODES PER LINE
      XPOS = XSPOS
C
      DO 88 NOD = 1,NDPL                      ! PLOT CURRENT ROW OF DIODES
      CALL CIRCLE(XPOS,YPOS,0.0,,DRIL,6)      !LENS MOUNTING PLATE HOLE SIZE
      CALL CIRCLE(XPOS,YPOS,0.0,,R,6)         ! LENS OUTLINE
      YPPP = YPOS + PPO                       ! PUNCH POINT OFFSET
      CALL PLOT(XPOS,YPPP,3)                  ! START OF PUNCH POINT
      YPPP = YPOS - PPO                       ! BOTTOM OF PUNCH POINT
      CALL PLOT(XPOS,YPPP,2)                  ! PEN DOWN
      XPPP = XPOS - PPO                       ! LEFT SIDE OF PUNCH POINT
      CALL PLOT(XPPP,YPOS,3)                  ! PEN UP
      XPPP = XPOS + PPO                       ! RIGHT SIDE OF PUNCH POINT
      CALL PLOT(XPPP,YPOS,2)                    PEN DOWN
      XPOS = XPOS + DIAMM
C
C     DO 90 IDLE1 = 1,50
C     DO 90 IDLE  = 1,1000                    ! WAIT LOOP TO LET PLOTTER
90    CONTINUE                                ! EMPTY BUFFER
C
88    CONTINUE                                ! COLLUMN LOOP
      YPOS = YPOS - DIAMM * COS(PI/4.)
99    CONTINUE                                ! ROW LOOP
C
```

```
      READ  (1,54) XLEN,YLEN
54    FORMAT (2F6.1)
      READ  (1,55) LINTYP,INTEQ
55    FORMAT (2I3)
      READ  (1,56) FCHAR
56    FORMAT (1A1)
      IF (FCHAR.EQ.'Y') AXOMIT = .TRUE.
C
C  READ DATA POINTS
      NPTS = 0
60    READ(1,70,END=222) X,Y
70    FORMAT(2F20.10)
      IF (X.EQ.999999.999) GOTO 109
      NPTS=NPTS+1
      XARRAY(NPTS)=X
      YARRAY(NPTS)=Y
      GO TO 60
C
C     Once all of the x- and y-values have been read into the
C     system's memory, close the file.
C
109   CLOSE (UNIT=1)
C
C  TITLE POSITIONING
C
      IF (AXOMIT) GOTO 110
      TITLEX = 1.0
      FILEY  = YLEN - 0.26
      TITLEY = FILEY - 0.5
      DSCPTY = TITLEY - 0.5
C
C  SET UP SCALING
C
110   DELTAX = (XMAX-XMIN)/XLEN
      DELTAY = (YMAX-YMIN)/YLEN
C
      XARRAY(NPTS+1) = XMIN
      XARRAY(NPTS+2) = DELTAX
C
      YARRAY(NPTS+1) = YMIN
      YARRAY(NPTS+2) = DELTAY
      NXCHAR = -1 * NXCHAR          ! TO PUT LABLE UNDER X-AXIS
C
C     WRITE (TLUN,398) YMIN,YMAX,YLEN,XLEN
C398  FORMAT(/' YMIN',F4.1,'   YMAX',F4.1,'   YLEN',F4.1,'   XLEN',F4.1)
C     WRITE (TLUN,399)
C399  FORMAT(/'     NPTS,NTCHAR,NDCHAR,NXCHAR,NYCHAR,DELTAX,DELTAY')
C     WRITE (TLUN,400) NPTS,NTCHAR,NDCHAR,NXCHAR,NYCHAR,DELTAX,DELTAY
C400  FORMAT (/'  ,5I7,'  ',2F6.2)
C
C     Plot the graph
C
600   CALL LINE(XARRAY,YARRAY,NPTS,1,LINTYP,INTEQ)
C
      IF (AXOMIT) GOTO 500
C
C     Plot the AXES
C
300   CALL AXIS(0.0,0.0,XNAM(1),NXCHAR,XLEN,0.0,XMIN,DELTAX)
C
400   CALL AXIS(0.0,0.0,YNAM(1),NYCHAR,YLEN,90.0,YMIN,DELTAY)
C
```

```
      YSYM = 24.0
      CALL SYMBOL(3.0,YSYM,0.3,'ARAYD1.FTN',0.0,10)
      YSYM = YSYM - .6
      CALL SYMBOL(3.0,YSYM,0.3,'LENS DIAMETER     =',0.0,19)
      CALL NUMBER(10.0,YSYM,0.3,DIAM,0.0,3)
      YSYM = YSYM - .6
      CALL SYMBOL(3.0,YSYM,0.3,'NUMBER OF DIODES  =',0.0,19)
      CALL NUMBER(10.0,YSYM,0.3,TWOD,0.0,0)
C
      CALL PLOT(0.0,0.0,-3)          ! PURGE BUFFER
C
      END
```

```
C GRAFPLOT.FTN                          6/12/83
C
      PROGRAM GRAFPLOT
C
C  THIS PROGRAM PLOTS DATA FROM A DATA FILE WITH THE FOLLOWING FORMAT
C-----------------------------------------------------------------------
C LINE #)  DISCRIPTION              | # OF CHARS | UNITS  | EXAMPLE
C      |                            |            |        |
C   1  |  TITLE                     |  UP TO 64  | ASCII  | DAS DATA
C   2  |  PLOT DESCRIPTION          |  UP TO 64  | ASCII  | FUEL VS TIME
C   3  |  X-AXIS LABLE              |  UP TO 32  | ASCII  | X-AXIS
C   4  |  Y-AXIS LABLE              |  UP TO 32  | ASCII  | Y-AXIS
C   5  |  MIN X,MAX X,MIN Y,MAX Y   |  F6.1      | ENG    | 0.0,10.0,0.0,10.0
C   6  |  X-LENGTH, Y-LENGTH        |  F3.1      |PAPER CM| 30.0,20.0
C   7  |  LINE TYPE, SYMBOL #       |  INTEGER   |        | 0,0
C   8  |  AXIS OMIT FLAG            |  1         | ASCII  | N
C   9  |  X1,Y1                     |  F9.3      | ENG    | 1.0,2.1
C  10  |  X2,Y2                     |  F9.3      | ENG    | 2.0,4.3
C   .  |   . .                      |  F9.3      | ENG    | 3.0,4.5
C   .  |   . .                      |  F9.3      | ENG    | 4.0,4.7
C   .  |   . .                      |  F9.3      | ENG    | 5.0,4.9
C 10+N |  XN,YN                     |  F9.3      | ENG    | 8.0,5.5
C 11+N |  TERMINATION CHARACTERS    |  F9.3      | REAL   | 999999.999,0.0
C
C  N (NUMBER OF POINTS) MAY BE 1 TO 100
C
C-----------------------------------------------------------------------
C
      REAL    XARRAY(200),YARRAY(200)
      INTEGER TLUN
      LOGICAL AXOMIT
      BYTE    XNAM(32),YNAM(32),FCHAR
      BYTE    FILNAM(16),TITLE(64),DSCPTN(64)
C
      TLUN = 7        ! TERMINAL LOGICAL UNIT NUMBER
C
      AXOMIT = .FALSE.
C
C     Initialize the plotter and redefine the origin
C
10    CALL PLOTS(0,0,4)
      CALL PLOT (2.0,2.0,-3)          ! DEFINE ORIGIN
C
C     Read the filename, open the file
C
      WRITE(TLUN,40)
40    FORMAT(' Filename > '$)
      READ(TLUN,50) NFCHAR,FILNAM
50    FORMAT(Q16A1)
      FILNAM(NFCHAR+1) = 0
      OPEN(UNIT=1,TYPE='OLD',NAME=FILNAM)
C
C  READ HEADER INFORMATION
C
      READ   (1,51) NTCHAR,TITLE
51    FORMAT (Q64A1)
      READ   (1,51) NDCHAR,DSCPTN
      READ   (1,52) NXCHAR,XNAM
52    FORMAT (Q32A1)
      READ   (1,52) NYCHAR,YNAM
      READ   (1,53) XMIN,XMAX,YMIN,YMAX
53    FORMAT (4F6.1)
```

```
      CALL PLOT(0.0,0.0,-3)                    ! PURGE BUFFER
C
C SYMBOL (XPAGE,YPAGE,HEIGHT,TEXT,ANGLE,NCHAR)
      YSYM = 24.0
      CALL SYMBOL(3.0,YSYM,0.3,'ARAYPL.FTN',0.0,10)
      YSYM = YSYM - .6
      CALL SYMBOL(3.0,YSYM,0.3,'LENS DIAMETER     =',0.0,19)
      CALL NUMBER(10.0,YSYM,0.3,DIAM,0.0,5)
      YSYM = YSYM - .6
      CALL SYMBOL(3.0,YSYM,0.3,'NUMBER OF DIODES  =',0.0,19)
      CALL NUMBER(10.0,YSYM,0.3,TNOD,0.0,0)
C
      CALL PLOT(0.0,0.0,-3)                    ! PURGE BUFFER
C
      END
```